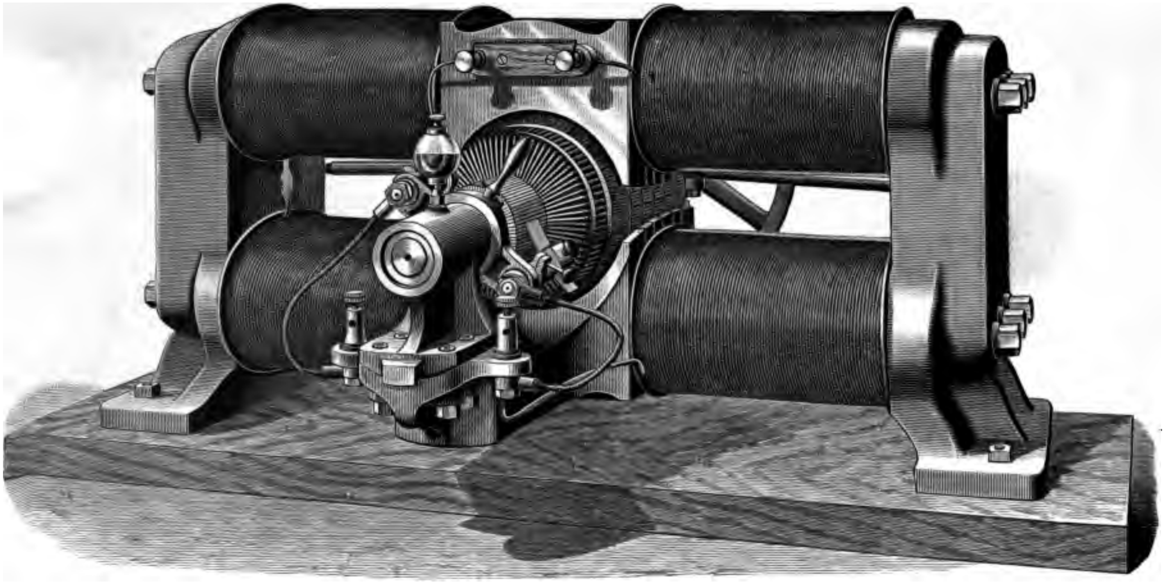


Dynamo-electric Machine. (For description, see p. 281.)

THE

CHAUTAUQUA COURSE

IN

PHYSICS

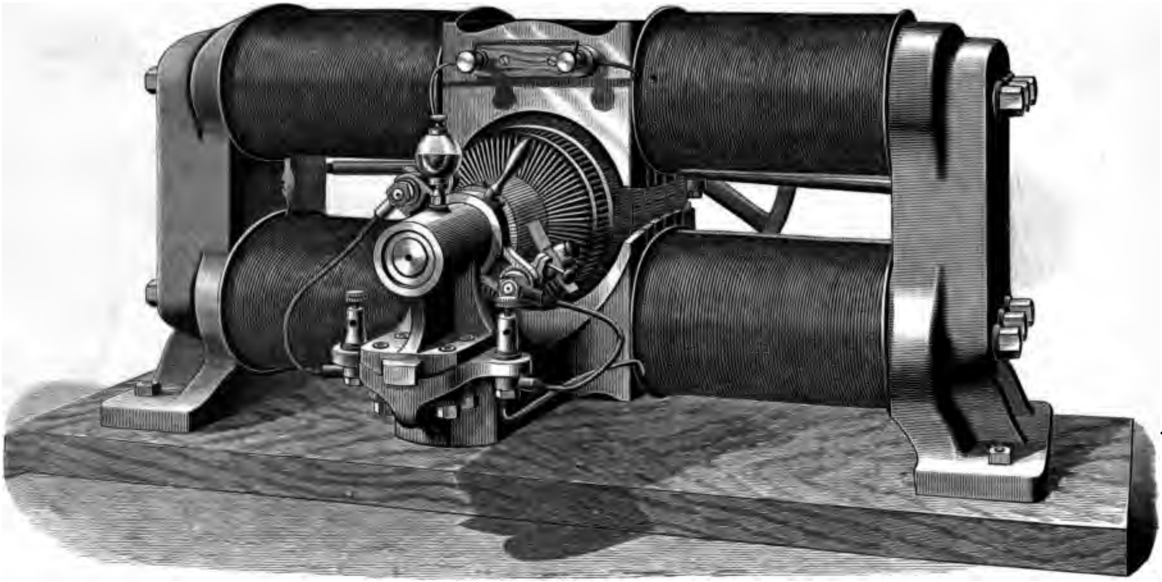
BY

J. DORMAN STEELE, PH.D., F.G.S

AUTHOR OF A POPULAR SERIES IN NATURAL SCIENCE

NEW YORK

CHAUTAUQUA PRESS



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The required books of the C. L. S. C. are recommended by a Council of six. It must, however, be understood that recommendation does not involve an approval by the Council, or by any member of it, of every principle or doctrine contained in the book recommended.

AUTHOR'S PREFACE.

THIS revision of a popular work has been made in the interest of those who, by individual effort, are pursuing a course of systematic reading. It does not belong to the class of books described as "science made easy," nor is it in any sense an exhaustive treatise. It presents with clear statement and practical illustration the chief laws which underlie the familiar phenomena of nature. That knowledge of principles which becomes the man or woman of general culture may be gained from these pages; technical information and mathematical calculations must be sought in more advanced works.

A science such as Physics is, in a broad sense, the systematic arrangement of observed facts, grouped with reference to the causes of which they are the effects. In scientific pursuits the reader of mature years has a marked advantage over the young student. The former has gained from experience a more or less wide knowledge of physical phenomena, which may easily be connected with an announced law, while the latter must be taught not only the principle, but the phenomena as well. The experience of the older, out of school, student

will largely compensate for the absence of apparatus, for which, moreover, the copious illustrations of this volume are an excellent substitute.

The self-educator would do well, then, to regard this book as an assistant in systematizing the information which he, in a large measure, already possesses. Let him observe the actual operation of law, and try to explain scientifically any facts which confront him in every-day life. Thus may the earnest student become a lover and interpreter of Nature, and come at last to see that Nature is but a "thought of God."

REFERENCE BOOKS

USED IN THE COMPILATION OF THIS VOLUME.

AIRY.....................Geometrical Optics.
American Cyclopedia.
ANTHONY AND BRACKETT.Text-book of Physics.
ARNOTT..................Elements of Physics.
ATKINSON................Deschanel's Natural Philosophy.
" ....Ganot's Physics.
" ....Elements of Electric Lighting.
BEALE...................How to Work with the Microscope.
CHEVREUL................Colors.
COOKE...................Religion and Chemistry.
DANIELL.................Principles of Physics.
Electrical Review.
FARADAY.................Forces of Matter.
HERING..................Principles of Dynamo-electric Machinery.
HERSCHEL................Introduction to the Study of Physical Science.
LOCKYER.................Guillemin's Forces of Nature.
" ....Studies in Spectrum Analysis.
" ....The Spectroscope.
LOOMIS..................Meteorology.
MARTIN AND WETZLER...The Electric Motor and its Applications.
Electrical World.
MAURY...................Physical Geography of the Sea.

MAXWELL... ....Electricity and Magnetism.
MILLER ....Chemical Physics.
NUGENT..................Optics.
ROSCOE..................Spectrum Analysis.
SCHELLEN................Spectrum Analysis.
Scientific American.
SILLIMAN.................Physics.
SNELL....................Olmsted's Philosophy (revised edition).
STEWART.................Conservation of Energy.
" ....Elementary Physics.
" ....Treatise on Heat.
TAIT.....................Recent Advances on Physical Science.
THOMPSON, SILVANUS.....Lessons in Electricity and Magnetism.
THOMSON AND TAIT.......Natural Philosophy.
TOMLINSON...............Introduction to the Study of Natural Philosophy.
TYNDALL.................Lectures on Light, Heat, Electricity, and Forms of Water.
URBANITZKY..............Electricity in the Service of Man.
YOUMANS ....Correlation of Physical Forces.

Also numerous works named in the "Reading References" at the close of the book.

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CHAPTER I.

INTRODUCTION.

"We have no reason to believe that the sheep or the dog, or indeed any of the lower animals, feel an interest in the laws by which natural phenomena are regulated. A herd may be terrified by a thunder-storm; birds may go to roost, and cattle return to their stalls during a solar eclipse; but neither birds nor cattle, so far as we know, ever think of inquiring into the causes of these things. It is otherwise with man. The presence of natural objects, the occurrence of natural events, the varied appearances of the universe in which he dwells, penetrate beyond his organs of sense, and appeal to an inner power of which the senses are the mere instruments and excitants. No fact is to him either final or original. He can not limit himself to the contemplation of it alone, but endeavors to ascertain its position in a series to which the constitution of his mind assures him it must belong. He regards all that he witnesses in the present as the afflux and sequence of something that has gone before, and as the source of a system of events which is to follow. The notion of spontaneity, by which in his ruder state he accounted for natural events, is abandoned; the idea that nature is an aggregate of independent parts also disappears, as the connection and mutual dependence of physical powers become more and more manifest; until he is finally led to regard Nature as an organic whole, as a body each of whose members sympathizes with the rest, changing, it is true, from age to age, but without any real break of continuity, or interruption of the fixed relations of cause and effect."

TYNDALL.

In ancient times, any seeker after truth was termed a philosopher (a lover of wisdom), and philosophy included all investigations concerning both mind and matter. In the fourth century B.C., Plato assumed that there are two principles, matter and form, which by combining produce the five elements: earth, air, fire, water, and ether. Aristotle, his pupil, established the first philosophical ideas concerning matter and space. But the method of study generally pursued for 2,000 years was one of pure metaphysical speculation. Observation had no place, but the philosophers made up a theory, and then accommodated facts to it. They guessed about the real essence of things, as to whether matter exists except when perceived

by the mind, and how a change in matter can produce a change in mind. Dr. Johnson once remarked to a gentleman who had been defending the theory that there is no external world, as he was going away: "Pray, sir, don't leave us; for we may perhaps forget to think of you, and then you will cease to exist." In 1620, Bacon published his "Novum Organum," advocating the inductive method of studying nature. He argued that the philosopher should seek to benefit mankind, and that, instead of wasting his time in sterile and ingenious theories about the world and matter, he should watch the phenomena of life, gather facts, and then reasoning from effects back to their causes, reach the general law. This work is commonly said to have established the modern method of investigation. Ptolemy, Archimedes, Galileo, and other physicists, however, had long before proved its value.

GENERAL DEFINITIONS.

Matter.

Whatever occupies space is called matter. A definite portion of matter, such as a lake, a dew-drop, a quart of oil, an anvil, a pendulum, is termed a body. A particular kind of matter, such as gold, wood, stone, oxygen, is styled a substance.

General and Specific Properties.

A general property of matter is a quality, like extension, that belongs to all substances. A specific property, like the yellow of gold, the brittleness of glass, the sweetness of sugar, is one which distinguishes particular substances. These are so distinctive that we say "yellow as gold," "brittle as glass," "sweet as sugar."

The Atomic Theory.

The Atomic Theory supposes that the smallest particle of matter we can see is composed of still smaller particles or molecules (tiny masses), each possessing the specific properties of the substance to which it belongs, and that each molecule consists of indivisible portions, called atoms, which can not be changed by any material force. A molecule is a group of atoms held together by chemical power, and is the smallest particle of a substance which can *exist by itself. Even in* a simple substance, in which the atoms

are all of one kind, it is thought that they are generally clustered in molecules. In water, the molecules are the small masses which, when driven apart, form steam. In gas, they move like so many worlds through space. Striking against the sides of the containing vessel, they produce the pressure of the gas, and cause this to escape if the vessel be opened.

A molecule of water is made up of two atoms of hydrogen and one of oxygen. A molecule of salt consists of one atom of chlorine and one of sodium. By dissolving in water we divide it into its separate molecules, and the solution has a briny taste, because each one possesses the savor of salt.

Animalcules furnish a striking illustration of the minuteness of atoms. In the drop of water that clings to the point of a needle, swarming legions swim as in an ocean, full of life, frisking, preying upon one another, waging war, and re-enacting the scenes of the great world about them. These tiny animals possess organs of digestion and assimilation. Their food, coursing in channels more minute than we can conceive, may be composed of solid as well as liquid matter; and finally, at the lowest extreme of this descending series, we come to the atoms of which the matter itself is composed. The most powerful of microscopes fails completely to reveal the separate molecule.

Physical and Chemical Changes.

A physical change is one that does not destroy the molecule, and so does not alter the specific properties of a substance; thus, the falling of a stone to the ground, the dissolving of sugar in water, are physical changes. A chemical change, however, is one that implies a re-arrangement of the atoms into new molecules, and so destroys the specific properties of a substance, as the rusting of iron or the burning of coal.

Energy.

The power of producing change of any kind is called energy. When it is manifested in producing some particular kind of change we speak of it as force.

Physical and Chemical Forces.

A physical force is one that produces a physical change in matter. Heat when it changes water into steam, light when it illumines a room, and magnetism when it causes a knife-blade to *attract a needle,* are examples of physical force. Chemical forc

is that which produces a chemical change, as when sand and soda are united by chemical force to make glass.

The same energy may be manifested successively in different kinds of force; thus, heat turns water into steam, which turns the wheel of an engine; this motion may be given to part of a dynamo-electric machine, and be transformed into electricity, magnetism, light, heat, and sound.

Physics. The most general definition of Physics is "the science of matter and energy." Commonly a distinction is made between Physics and Chemistry. Physics relates to changes that involve masses and molecules of matter; Chemistry to those that affect the atoms of matter.

The Atomic Theory was propounded by Democritus, in the fifth century B. C., and twenty-two centuries later elaborated by Dalton, an English physicist. The grander generalization and development of this law was advanced in 1811 by Avogadro, an Italian, and afterward extended by the French philosopher, Ampère. The latter asserted that "equal volumes of all substances, when in the gaseous form and under like conditions, contain the same number of molecules." For half a century this view lay dormant. Of late it has borne fruit, and the molecular theory has become to Chemistry what the law of gravitation is to Astronomy. The labors of Thomson, Cooke, Tait, and others are now building up the whole superstructure of Chemistry and Physics upon this basis.

GENERAL PROPERTIES OF MATTER.

There are two essential properties without which matter is inconceivable. These are extension and impenetrability.

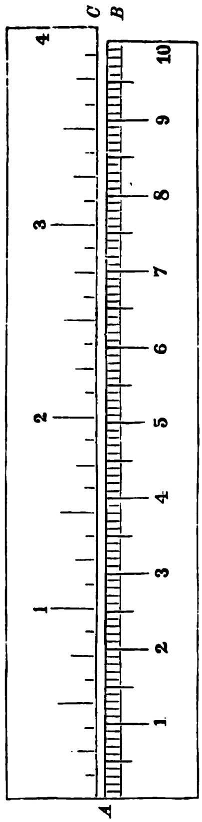
Extension. Extension is the property of occupying space. The amount of space a body occupies is called its volume. A body has three dimensions: length, breadth, and thickness. To measure these, some standard is required. The standard of length popularly in use in England and the United States is the yard. Its length is the distance between two lines on a certain bar of bronze, kept *in London and* measured at a certain temperature, 62° F.

There is only one yard in the world; all that we call yards are imperfect copies from it. The yard is inconveniently divided into three feet, or thirty-six inches. The standard of length used in France, and by scientific men throughout the world, is the meter. Its length is nearly, but not exactly, $\frac{1}{10\,000\,000}$ of an entire meridian of the earth. There is only one meter in the world. It is the length of a certain bar of platinum, kept in Paris, and measured at the temperature of melting ice.

The Metric System.

Most copies of the meter and yard are accurate enough for the purposes to which they are applied.

FIG. 1.



Comparison of Metric and English Measures of Length.

The meter is divided into ten decimeters (*dm.*); each of these into ten centimeters (*cm.*); and each of these into ten millimeters (*mm.*). In Fig. 1 is shown a line, AB, whose length is a decimeter, divided into centimeters and millimeters. At the side of it is another line, AC, slightly longer. It is made up of four inches, divided into halves, quarters, and eighths. The length of the meter is about 39.37 inches, or nearly 1.1 yards.

For the measurement of surface, we use square meters (*sq. m.*), square centimeters (*sq. cm.*), etc.

The unit adopted for the measurement of volume is the cubic decimeter. It is called a liter. A vessel that contains just a liter of water will hold a little more than a quart of the same liquid. Since the liter has a length, breadth, and thickness of one decimeter, it contains 1,000 cubic centimeters.

The history of the establishment of a standard of measures is a *curious* one. Anciently, length was referred to *some portion of the* human body, as the foot; the cubi

(the length of the fore-arm from the elbow to the end of the middle finger); the finger's length or breadth; the hand's breadth; the span, etc. In England, Henry I. (1120) ordered that the ell, the ancient yard, should be the exact length of his arm. Afterward a standard yard-stick was kept at the Exchequer in London; but it was so inaccurate, that a commissioner, who examined it in 1742, wrote: "A kitchen poker filed at both ends would make as good a standard. It has been broken, and then repaired so clumsily that the joint is nearly as loose as a pair of tongs." In 1760, Mr. Bird carefully prepared a copy of this for the use of the government. It was not legally adopted until 1824, when it was ordered that if destroyed, it should be restored by a comparison with the length of a pendulum vibrating seconds at the latitude of London. At the great fire in London, 1834, the Parliament House was burned, and with it Bird's yard-stick. Repeated attempts were then made to find the length of the lost standard by means of the pendulum. This was found impracticable, on account of errors in the original directions. At last the British government adopted a standard prepared from the most reliable copies of Bird's yard-stick. A copy of this was taken by Troughton, an instrument-maker of London, for the use of our Coast Survey. A bronze bar, which has the standard length at 61.79° F., has been presented by the English government to that of the United States. According to Act of Congress, sets of weights and measures have been distributed to the governors of the several States. Both the yard and the meter are legal standards in the United States and Great Britain.

The French had previously adopted for the length of the legal foot that of the royal foot of Louis XIV., as perishable a standard as Henry's arm. In 1790, the Prince de Talleyrand proposed to the Constituent Assembly of France the foundation of a system based on a single and universal standard, which might be used by all civilized nations. The selection of this was committed to five members of the Academy of Sciences, MM. Borda, Lagrange, Laplace, Monge, and Condorcet, who decided that the ten-millionth part of a quarter of the earth's meridian should be taken as the standard of length, from which the standards of surface, volume, capacity, and weight should

be derived. A trigonometric measurement was made of the arc of a meridian extending through France from Dunkirk to Barcelona, a work which occupied seven years. In 1799, an international commission was assembled at Paris, with representatives from most of the governments of Europe. They deposited at the Palace of the Archives, in Paris, the standard meter-bar of platinum, and the standard kilogram weight, made of the same metal. In English denominations the length of the meter is almost exactly 3.28 feet, or 39.37 inches; the weight of the kilogram almost exactly 2.2 pounds avoirdupois.

But after the establishment of the metric system it was found that a slight mistake had been made in the measurement of the arc of the meridian. The English, who had declined to accept the French system, discovered also a difficulty in the determination of the yard from the pendulum beating seconds. Both the yard and the meter are therefore arbitrary and not absolute standards. Copies of each have been made so carefully and distributed so widely that there is no probability of any appreciable loss resulting from the accidental destruction of the originals. The metric system is by far the simplest and best in use, but it has not yet generally supplanted other systems that retain their popularity, not on account of merit, but only because of human conservatism and the inconveniences resulting from change.

Impenetrability.

Impenetrability is the property of so occupying space as to exclude all other matter. No two bodies can occupy the same space at the same time. A book lies upon the table before me; no human power is able to place another in the same spot, until the first book is removed. I attempt to fill a bottle through a closely-fitting funnel; but before the liquid can run in, the air must gurgle out, or the water will trickle down the outside of the bottle.

In common language, we say a needle penetrates cloth, a nail enters wood, etc.; but a moment's examination shows that they merely push aside the fibers of the cloth or wood, and so press them closer together. With care we can drop a quarter of a pound of shingle-nails into a tumbler brimful of water, without causing it to overflow. The surface of the water, however, becomes convex.

In addition to these two essential properties of matter, there are others which have been found to be general, such as divisibility, porosity, and indestructibility.

Divisibility. Divisibility is that property by which a body may be separated into parts. The extent to which the divisibility of matter may be carried is almost incredible. A grain of strychnine will flavor 1,750,000 grains of water; hence there will be in each grain of the liquid only $\frac{1}{1\,750\,000}$ of a grain of strychnine, yet this amount can be distinctly tasted.

Newton estimated that the film of a soap-bubble at the instant of breaking is less than $\frac{1}{2\,600\,000}$ of an inch thick. Pure water will acquire the requisite viscidity for making bubbles by adding only $\frac{1}{100}$ part of soap. It is evident that there must be at least one molecule of soap in every cubic $\frac{1}{2\,600\,000}$ of an inch of the film, and that the molecule must be smaller than one hundredth of a cubic $\frac{1}{2\,600\,000}$ of an inch, *i. e.*, than $\frac{1}{260\,000\,000}$ of a cubic inch. Now a molecule of soft-soap (if it is a pure potassium stearate) contains 56 atoms, and this point must be reached before we come to the possible limit of divisibility.

Porosity. Porosity is the property of having pores. By this is meant not the sensible pores to which we refer when in common language we speak of a porous body, as bread, wood, unglazed pottery, a sponge, etc., but the finer or physical pores. The latter are as invisible to the eye as the atoms themselves, and are caused by the fact that the molecules of which a body is composed are not in actual contact, but are separated by minute spaces. These spaces are so small that they can not be discerned with the most powerful microscope, yet it is thought that they may be very large when compared with the size of the atoms themselves. If we imagine a being small enough to live on one of the atoms near the center of a stone, as we live on the earth, then we are to suppose that he might possibly see the nearest atoms at great distances from him, as we see the moon and stars, and might perchance have need of a fairy telescope to examine them, as we investigate the heavenly bodies. It is impossible, however, for us to have any definite knowledge on *such a topic.*

To a bowl-full of water it is easy to add a quantity of fine salt without the liquid running over. Only care must be taken to drop in the salt slowly, giving time for it to dissolve and the bubbles of air to pass off. When the water has dissolved all the salt it can, we can still add other soluble solids. In this case we suppose that the particles of salt are smaller than those of water, and those of the different substances used are smaller than those of salt. The particles of salt fill the spaces between the particles of water, and the others occupy the still smaller spaces left between the particles of salt. We may better understand this if we suppose a bowl filled with oranges. It will hold a quantity of peas, then of gravel, then of fine sand, and lastly some water.

In testing large cannon by hydrostatic pressure, water is forced into the gun until it oozes through the thick metal and covers the outside of the gun like froth, then gathers in drops and runs to the ground in minute streams. In the course of some experiments performed during the eighteenth century at the Florence Academy, Italy, hollow globes of silver were filled with water and placed in a screw-press. The spheres being flattened, their size was diminished, and the water oozed through the pores of the metal. The philosophers of the day thought that this showed water to be incompressible. We now see that it proved only that silver has pores larger than the molecules of water.

It is in virtue of these physical pores that a body changes in volume when warmed or cooled. The molecules become farther apart or nearer as heat is applied or withdrawn. We can not conceive this to be possible if they are in perfect contact.

Indestructibility.

Indestructibility is the property which renders matter incapable of being destroyed. We can not conceive of the annihilation of matter. We may change its form, but we can not deprive it of existence. Suppose we cut down a tree, saw it into boards, and build a house. The house burns, and only little heaps of ashes remain. Yet in the ashes, and in the smoke of the burning building, exist the identical atoms, which have passed through these *various forms* unchanged. Walter Raleigh, while smoking *in the presence of* Queen Elizabeth, offered to bet her Majesty

that he could tell the weight of the smoke that curled upward from his pipe. The wager was accepted. Raleigh quietly finished, and then weighing the ashes, subtracted this amount from the weight of the tobacco he had placed in the pipe, thus finding the weight of the smoke. The student of chemistry will be able to detect Raleigh's mistake. The smoke and the ashes really weighed more than the original tobacco, since the oxygen of the air had combined with the tobacco in burning.

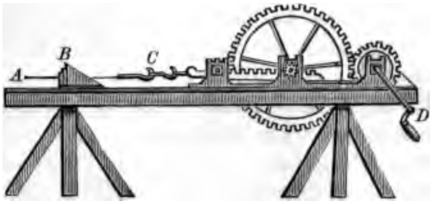
SPECIFIC PROPERTIES OF MATTER.

Among the most important specific properties of matter are ductility, malleability, tenacity, elasticity, hardness, and brittleness.

Ductility.

A ductile body is one which can be drawn into wire. Fig. 2 represents a machine for making wire. *B* is a steel drawing-plate pierced with a series of gradually diminishing holes. A rod of iron, *A*, is hammered at the end so as to pass through the largest. It is then grasped by a pair of pincers, *C*, and, by turning the crank, *D*, is drawn through the plate, diminished in diameter and proportionately increased in length. The tenacity of the metal is greatly improved by the process of drawing, so that a cable of fine wire is stronger than a chain or bar of the same weight. Gold, silver, and platinum are the most ductile metals. A silver rod an inch thick, covered with gold leaf, may be drawn to the fineness of a hair and yet retain a perfect coating of gold, three ounces of the latter metal making 100 miles of the gilt-thread used in embroidery. Platinum wire has been drawn so fine that, though it is nearly three times as heavy as iron, a mile's length weighed only a grain.

FIG. 2



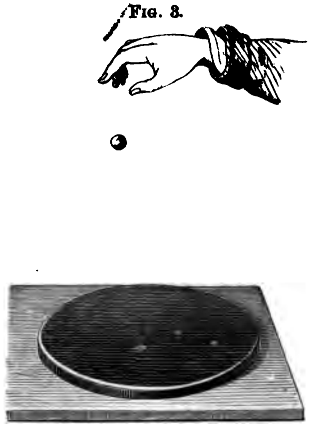
Drawing Wire.

A malleable body is one which can be hammered or rolled

into sheets. Gold may be beaten until it is only $\frac{1}{360000}$ of an inch thick. It would require 1,800 such leaves to equal the thickness of common printing-paper. An ingot of gold is passed many times between steel rollers, which are so adjusted as to be continually brought nearer together. The metal is thus reduced to a ribbon about $\frac{1}{800}$ of an inch thick. This is cut into inch squares, 150 of which are piled up alternately with leaves of strong paper four inches square. A workman with a hammer beats the pile until the gold is spread to the size of the leaves. Each piece is next quartered, and the 600 squares are placed between leaves of goldbeaters' skin and pounded. They are then taken out, spread by the breath, cut, and the 2,400 squares pounded as before. They are finally trimmed and placed between tissue-paper in little books, each of which contains twenty-five gold leaves. Copper is so malleable, that a workman can hammer out a kettle from a solid block.

Malleability.

Fig. 3.



Elasticity of Ivory.

A tenacious body is one which can not easily be pulled apart. Iron possesses this quality in a remarkable degree. Steel wire will sustain many thousand times its own weight.

Tenacity.

Elasticity is of four kinds, according as a body tends to resume its original form when compressed, extended, twisted, or bent.

Elasticity.

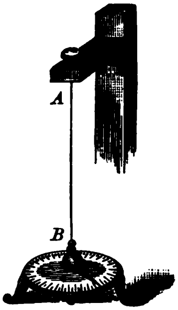
Many solids, as iron, glass, and caoutchouc, illustrate the elasticity of compression. Spread a thin coat of oil on a smooth marble slab. If an ivory ball be dropped upon it, the size of the impression will vary with the distance at which the ball is held above the table. This shows that the ivory is flattened, somewhat like a soap-bubble when it strikes a smooth surface and rebounds. Liquids are compressed

with great difficulty, so that for a long time they were considered incompressible. When the force is removed, they regain their exact volume, and are therefore perfectly elastic. Gases are easily compressed, and are also perfectly elastic. A pressure of fifteen pounds to the square inch reduces the volume of water only $\frac{1}{20000}$, whereas it diminishes the volume of a perfect gas one half. A gas may be kept compressed for years, but on being released will instantly return to its original form.

Elasticity of expansion is possessed largely by many substances. India rubber, when stretched, tends to fly back to its original dimensions. A drop of water at the nozzle of a bottle may be touched by a piece of glass and drawn out to considerable length, but when let go it will resume its spherical form.

The elasticity of torsion is the tendency of a thread or wire which has been twisted, to untwist again. If a weight be suspended by a steel wire, twisted and then released, it constitutes a torsion pendulum.

FIG. 4.



The Torsion Pendulum.

Elasticity of flexure is the property ordinarily meant by the term elastic. Many solids possess this quality to a high degree. Swords have been made which could be bent into a circle without breaking. Watch-springs, bows, etc., are useful because of their elasticity. Glass, though brittle, is one of the most elastic substances known.

Hardness.

One body is harder than another when it will scratch or indent it. This property does not depend on density. Gold is about $2\frac{1}{2}$ times as dense as iron, yet it is much softer.—Mercury is a liquid, yet it is almost twice as dense as steel.—The diamond is the hardest known substance, yet it is not one third as heavy as lead. A dense body has its molecules closely compacted. The word rare, the opposite of dense, is applied to gases. Mass, or the quantity of matter a body contains, should be distinguished from weight or size.

Brittleness.

A brittle body is one that is easily broken. This property is a frequent characteristic of hard bodies. *Glass will* scratch pure iron, yet it is extremely brittle.

CHAPTER II.

MOTION AND FORCE.

Rest is nowhere. The winds that come and go, the ocean that uneasily throbs along the shore, the earth that revolves about the sun, the light that darts through space—all tell of a universal law of Nature. The solidest body hides within it inconceivable velocities. Even the molecules of granite and iron have their orbits as do the stars, and move as ceaselessly.

No energy is ever lost. It changes its form, but the eye of philosophy detects it and enables us to drive it from its hiding-place undiminished. It assumes Protean guises, but is every-where a unit. It may disappear from the earth; still—

> **"Somewhere yet that atom's force**
> **Moves the light-poised universe."**

Motion.

Motion is change of place. All motion, as well as rest, with which we are acquainted, is relative. When we ride in the cars, we judge of our motion by the objects around us.—A man on a steamer may be in motion with regard to the shore, but at rest with reference to the objects on the deck of the vessel. Force is that which produces or destroys motion. Velocity is the rate at which a body moves. It is expressed by the number of units of space through which the body moves in a unit of time, as ten miles an hour, or fifteen feet a second.

Communication of Motion.

The communication of motion is not instantaneous. A stone thrown against a pane of glass shatters it; but a bullet fired through it will make only a round hole. The bullet is gone before the motion has time to be given perceptibly to the surrounding particles.—A fraction of time is required for a ball to receive the force of the exploding powder and to get under full headway.

Press with all your might against a rock weighing a ton, and you will fail to move it if you press ever so long. The force *is not sufficient to* overcome the friction between the rock and the

ground. If, however, we could conceive the rock poised in empty space, the least touch would at once move it with a velocity proportional to the pressure divided by the mass. If you strike one end of a rail a mile long, the tremor will take a definite time to reach the other end. If, on the other hand, a powerful engine suddenly pulls at one end of the rail, so as to draw it over a considerable distance in a second, we can imagine that the other end will move after an almost infinitely short time; but if the engine drag the rail continuously, both ends will have the same velocity, and the whole rail will move together.

Resistances to Motion.

The resistances to motion are friction and the resistance of air and water. Friction is the resistance caused by the surface over which a body moves. It is of great value in common life. Without it, nails, screws, and strings would be useless; engines could not draw the cars; we could hold nothing in our hands; and we should every-where walk as on glassy ice. The resistance which a body meets in passing through air or water is caused largely by the particles displaced.

Laws of Motion.

There are three laws of motion, which were first distinctly formulated by Sir Isaac Newton.

First Law of Motion.

1st. A body set in motion will move forever in a straight line, unless acted on by some external force. Obviously, no experiment will directly prove this law. There is a curious illustration, however, in the swinging of a pendulum under the receiver of an air-pump. The better the exhaustion, the longer will the pendulum vibrate. In the best vacuum we can produce, it will swing for thirty or forty hours. It is supposed that if all resistances to motion were removed, the pendulum would never stop.

The law just stated is often called the law of inertia. Matter has no inherent power of producing change upon itself. If a body be already in motion, force has to be expended in stopping it. If it be at rest, force is required to start it in motion. In either case we "overcome its inertia." The danger in jumping from a car in rapid motion lies in the fact that *the body has the* speed of the train, while the forward motion

of the feet is checked by contact with the ground. It is necessary to jump as nearly as possible in the direction in which the train is moving, and be ready to run the instant the feet touch the ground. Those who do so can then gradually overcome the inertia of the body, and after a few yards can turn as they please.

To measure any force we must know first what quantity of matter is moved, and also what velocity it receives. The quantity of matter in a body is called its mass. It is not the same as weight, but is proportional to it, so that we speak of pounds of mass as well as pounds of weight. The product of mass by velocity is called momentum. Thus if a mass of five pounds move with a velocity of twenty feet per second, it has one hundred units of momentum.

A heavy body may be moving very slowly and yet have an immense momentum. An iceberg, with a scarcely perceptible motion, will crush the strongest ship as if it were an egg-shell. Soldiers have thought to stop a spent cannon-ball by putting a foot against it, but have found its momentum sufficient to break a leg.

On the other hand, a light body moving with a high velocity may have an enormous momentum. The air in a hurricane will tear up trees by the roots and level buildings to the ground. — Sand driven from a tube by steam is used for drilling and in stone-cutting, engraving, etc.

In a rude age, before the invention of means for overcoming friction, the weight of bodies formed the chief obstacle to setting them in motion. It was only after some progress had been made in the art of throwing missiles, and in the use of wheel-carriages and floating vessels, that men's minds became practically impressed with the idea of mass as distinguished from weight. Accordingly, while almost all the metaphysicians who discussed the qualities of matter, assigned a prominent place to weight among the primary qualities, few or none of them perceived that the sole unalterable property of matter is its mass. At the revival of science, this property was expressed by the phrase "The inertia of matter"; but while the men of science understood by this term the tendency of the *body to persevere in* its state of motion (or rest), and con-

sidered it a measurable quantity, those philosophers who were unacquainted with science understood inertia in its literal sense as a quality—mere want of activity or laziness. I therefore recommend to the student that he should impress his mind with the idea of mass by a few experiments, such as setting in motion a grindstone or a well-balanced wheel and then endeavoring to stop it, twirling a long pole, etc., till he comes to associate a set of acts and sensations with the scientific doctrines of dynamics, and he will never afterward be in any danger of loose ideas on these subjects.

Second Law of Motion.

2d. A force acting upon a body in motion or at rest, produces the same effect whether it acts alone or with other forces. All bodies upon the earth are in constant motion with it, yet we act with the same ease that we should were the earth at rest.

A ball thrown up into the air with a force that would cause it to rise fifty feet, will ascend to that height whatever horizontal wind may be blowing. — While riding on a car, we throw a stone at some object at rest. The stone, having the motion of the train, strikes just as far ahead of the object as it would have gone had it remained on the train. In order to hit the mark, we should have aimed a little back of it. — The circus-rider wishes, while his horse is at full speed, to jump through a hoop suspended before him. He simply springs directly upward. Going forward by the momentum which he had acquired before he leaped from the horse, he passes through the hoop and alights upon the saddle again. — A person riding in a coach drops a cent to the floor. It apparently strikes where it would if the coach were at rest.

We throw a stone directly at an object and hit it, yet, within the second, the mark has gone forward many feet, since the earth moves in its orbit around the sun at the rate of about eighteen miles per second.

If a cannon-ball be thrown horizontally, it will fall as fast and strike the earth as soon as if dropped to the ground from the muzzle of the gun. In Fig. 5, *D* is an arm driven by a wooden spring, *E*, and turning on a hinge at *C*. At *D* is a hollow containing a bullet, so placed that when the arm is *sprung, the ball* will be thrown in the line FK. At F is a

similar ball, supported by a thin slat, *G*, and so arranged that the same blow which throws the ball, *D*, will let the ball, *F*, fall in the line *FH*. The two balls will strike the floor at the same instant.

FIG. 5.

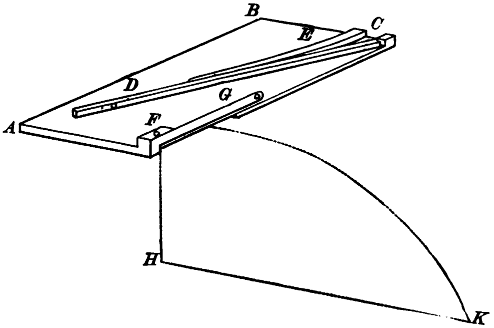


Illustration of the Second Law of Motion.

Third Law of Motion.

3d. Action is equal to reaction, and in the contrary direction. A bird in flying beats the air downward, but the air reacts and supports the bird.—The powder in a gun explodes with equal force in every direction, driving the gun backward and the ball forward, with the same momentum. Their velocities vary with their weights; the heavier the gun, the less will the recoil be noticed.—When we spring from a boat, unless we are cautious, the reaction will drive it from the shore.—When we jump from the ground, we tend to push the earth from us, while it reacts and pushes us from it; we separate from each other with equal momentum, and our velocity is as much greater than that of the earth as we are lighter.—We walk therefore by reason of the reaction of the ground on which we tread.

FIG. 6.

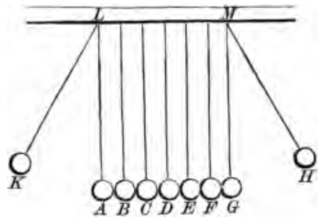


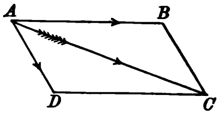
Illustration of the Third Law of Motion.

The apparatus shown in Fig. 6, consists of ivory balls hun

so as to vibrate readily. The same experiments can be performed by means of glass marbles or billiard balls placed in a groove. Better still, attach strings to glass marbles by means of mucilage and bits of paper, and suspend them from a simple wooden frame.

If a ball be let fall from one side, it will strike the second ball, which will react with an equal force, and stop the motion of the first, but transmit the motion to the third; this will act in the same manner, and so on through the series, each acting and reacting until the last ball is reached; this will react and then bound off, rising as high as the first ball fell (except the loss caused by resistances to motion). If two balls be raised, two will fly off at the opposite end; if two be let fall from one side and one from the other, they will respond alternately.

FIG 7.

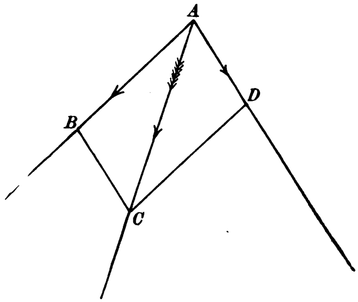


Composition of Motions.

Composition of Motions.

Let a ball at A (Fig. 7) be acted on by a force which would drive it in a given time to B, and also at the same instant by another which would drive it to D in the same time; the ball will move in the direction AC. This results from the composition of the two motions.—A person wishes to row a boat across a swift current which would carry him down stream. He therefore steers toward a point above that which he wishes to reach, and so goes directly across.—A bird, beating the air with both its wings, flies in a direction different from that which would be given by either one.

FIG. 8.



Composition of Two Forces.

Composition of Forces.

When a body is thus acted on by two forces, we draw lines representing their directions, and mark off AD and AB, whose *lengths represent* their comparative magnitudes. We next com-

plete the parallelogram and draw the diagonal AC, which denotes the resultant of these forces, and gives the direction in which the body will move. If more than two forces act, we find the resultant of two, then of that resultant and a third force, and so on.

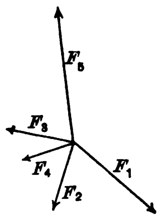
Triangle of Forces.

In Fig. 8, the resultant, AC, could have been obtained more easily by drawing AB to represent the magnitude and direction of one force, and then similarly BC for the other force. Connecting the initial point, A, of the first line with the terminal point, C, of the second line, we have AC for the magnitude and direction of the resultant, which completes a triangle.

Polygon of Forces.

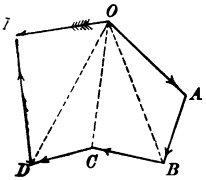
Let F_1, F_2, F_3, F_4, and F_5 (Fig. 9), represent five forces acting on the same point at the same time. To find their resultant, we draw (Fig. 10) OA, AB, BC, CD, and DE, equal and parallel respectively to F_1, F_2, F_3, F_4, and F_5. Then, joining the first point with the last, we have OE to represent the magnitude and direction of their combined resultant. For OB is the resultant for OA and AB; OC for OB and BC; OD for OC and CD; and OE for OD and DE. This method is applicable to the representation of any number of forces.

FIG 9.



Five Forces acting at the same Point.

FIG. 10.



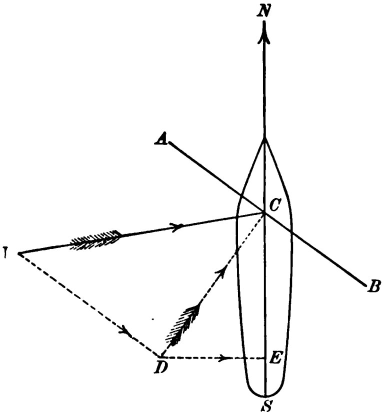
Polygon of Forces.

Resolution of Forces.

Resolution of forces consists in finding what forces are equivalent to a given force under special conditions. A triangle is drawn, having the given force as one side. There is a wind, blowing nearly from the west (Fig. 11) against the sail, AB, of a vessel going northward. We may regard the wind force, WC, as the resultant of two forces, WD and DC. The former, being parallel to the sail, is not effective; the latter is perpendicular to it, and tends to drive the vessel nearly north-east. Again, resolving DC, we find this equivalent to two forces, DE and EC. The former pushes the vessel sideways, but is largely counter-

acted by the resistance of the water against the broad side; EC is in the direction of the ship's course, and propels it north.

Fig. 11.

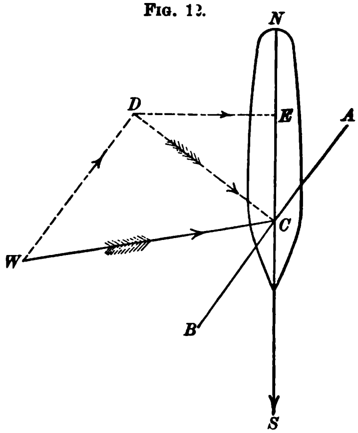


Resolution of Forces. Ship sailing northward.

By shifting the rigging, one vessel may sail into the harbor while another is sailing out, both driven by the same wind. In Fig. 12, which represents a ship sailing southward, the lettering and explanation is the same as for Fig. 11, if we substitute "south" for "north." If the ship were required to go westward, it would tack alternately NW and SW. In this way its resultant direction might be almost in the "teeth of the wind."

In a similar manner we may resolve the three forces which act upon a kite—viz., the pull of the string, the force of the wind, and its own weight. In Fig. 11, let AB represent the face of the kite. We can resolve WC, the force of the wind, into WD and DC. We next resolve DC into DE and EC. We then have a force, EC, which overcomes the weight of the kite, and tends to lift it upward. The string pulls in the direction CD, perpendicularly to the face. The kite obeys neither one of these forces alone, but both, and so ascends in a direction CA between the two. It is

Fig. 12.



Resolution of Forces. Ship sailing southward.

really drawn up an inclined plane by the joint force of the wind and the string.

A canal-boat drawn by horses is acted upon by a force which tends to bring it to the bank. This force may be resolved into two, one pulling toward the tow-path, and the other directly ahead. The former is counteracted by the shape of the boat and the action of the rudder; the latter draws the boat forward.

Motion in a Curve.

Whenever two or more instantaneous forces act upon a body, the path is a straight line. When one is instantaneous and the other continuous, it is a curved line. When a body is thrown into the air, except in a vertical line, it is acted upon by the instantaneous force of projection and the continuous force of gravity, and so describes a line which curves toward the earth.

Circular Motion.

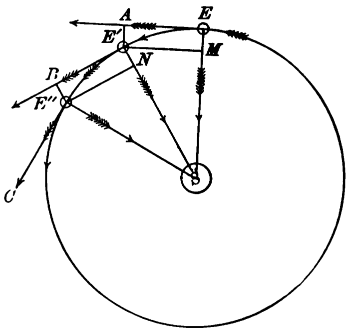
Circular motion is produced when a moving body is drawn toward a center by a constant force. Thus, when a sling is whirled, the stone is pulled toward the hand by the string, and as, according to the third law of motion, every action has its equal and opposite reaction, the hand is pulled toward the stone. If the string break, the stone will continue to move, according to the first law of motion, in a straight line in the direction of a tangent to the circle at that point. The tension of the string, acting inward, is called the Centripetal (*centrum*, the center, *petere*, to seek) force; and the reaction of the stone upon the string, acting outward, is termed the Centrifugal (*centrum*, the center, *fugere*, to flee) force.

It should be noticed that in circular motion there is but one true force concerned. It acts, however, upon a body in motion. The so-called centrifugal force has nothing to do with the production of the motion, being merely the resistance which the body offers by its inertia to the operation of the centripetal force, and ceases the instant that force is discontinued. It does not act at right angles to the centripetal force, as is often stated, but in direct opposition. A body never flies off from the center impelled by the centrifugal force, since that can never *exceed the centripetal* (action = reaction), and moreover *the path of such a body* is in the direction of a tangent, and

not the radius of a circle. Thus, when water is thrown off a grindstone in rapid rotation, the tendency of the water to continue to move on in the direction of the straight line in which it is going at each instant (in other words, the inertia of the water) overcomes its adhesion to the stone, and it flies off in obedience to the first law of motion. So, also, when a grindstone, driven at a high speed, breaks, and the fragments are thrown with great velocity, we are not to suppose that the centrifugal force impels them through the air. That force existed only while the stone was entire. It was opposed to the force of cohesion, and in the moment of its triumph ceased, and the fragments of the stone fly off in virtue of the velocity they possess at that instant. Again, the so-called centrifugal force is not a real force urging bodies upward at the equator. The earth's surface is merely falling away from a tangent, and a part of the force of gravity is spent in overcoming the inertia of bodies. The term centrifugal force has caused much confusion, and will perhaps be discarded.

The following examples are among those usually given to illustrate the action of the center-fleeing force: Water flies from a grindstone on account of the centrifugal force produced in the rapid revolution, which overcomes the adhesion.—In factories, grindstones are sometimes revolved with such velocity that this force overcomes that of cohesion, and the ponderous stones fly into fragments.—A pail full of water may be whirled around so rapidly, that none will spill out, because the centrifugal force overcomes that of gravity.—When a horse is running around a small circle, he bends inward to overcome the centrifugal force.

FIG. 13.



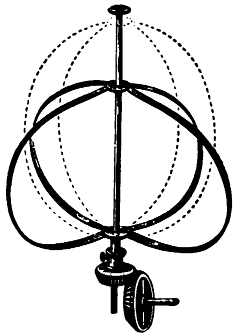
Circular Motion.

The heavenly bodies present the grandest example of circular motion. We may suppose the earth to have been moving originally in the direction *AE*. The attraction of the sun,

however, drawing it in the direction *ES*, it passes along the line *EE'*. If the centripetal force were suddenly to cease, the earth would fly off into space along a tangent, as *EA*. The rapid revolution of the earth on its axis tends to throw off all bodies headlong. As this acts in opposition to gravity, it diminishes the weight of bodies at the equator, where it is greatest, being there equivalent to $\frac{1}{289}$ of the force of gravity. It also tends to drive the water on the earth from the poles toward the equator. Were the velocity of the earth's rotation to diminish, the water would flow back toward the poles and tend to restore the earth to a spherical form. Since the earth's polar diameter is nearly twenty-seven miles shorter than its equatorial diameter, we are not sure that this motion of its waters would make it perfectly spherical.

This influence is well illustrated by the apparatus shown in Fig. 14. The hoop is made to slide upon its axis, and if revolved rapidly it will assume an oval form, bulging out more and more as the velocity is increased. This apparatus is accompanied by objects to illustrate the principle that all bodies tend to revolve about their shortest diameters. "Tie to the middle of a lead-pencil a piece of string about three feet long. Suspend so that the pencil will balance itself. Now twist the end of the string between the thumb and the first finger of the right hand, steadying and holding the string with the left hand. A circular motion will thus be communicated to the pencil, and it will revolve around the point on which it is suspended. Tie a piece of white string around the middle of the pencil, or its center of gravity, simply to show the position of that point. Now tie the first piece of string half-way between the end of the pencil and the center of gravity, and communicate the circular motion described above, and we shall observe that the pencil will still revolve around the center of gravity, the point marked by the white string being at rest. It can *thus be shown that* any thing, of whatever shape, will tend to

FIG. 14.



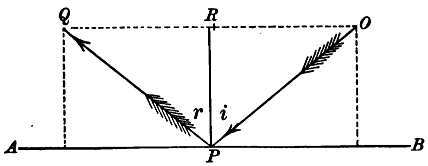
revolve on its shortest diameter. If the end links of a small steel chain (such as is often attached to purses or parasols) be hooked together, the string tied to a link, and the circular motion given, it will be observed that the chain begins to take an elliptical form, which gradually approaches that of a circle, until at last it becomes a circle, when it revolves horizontally. This shows that even a ring revolves on its shortest axis."

Aristotle taught that all motion is naturally circular, and this view was held by his school. He divided the phenomena of motion into two classes—the natural and the violent. As an instance of the former, he gave the falling of a stone, which constantly increases in velocity; and of the latter, a stone thrown vertically up, which, being against nature, continually goes slower. Newton, in his "Principia," published in 1687, propounded the laws of motion as now received. Other philosophers, notably Galileo, Hooke, and Huyghens, had anticipated much of his reasoning, yet so slowly were his opinions accepted that "at his death," says Voltaire, "he had not more than twenty followers outside of England."

Reflected Motion.

Reflected motion is produced by the reaction of a surface against which an elastic body is cast. If a perfectly elastic ball be thrown in the direction OP against the surface AB, it will rebound in the line PQ. The angle, i, between the direction OP and the perpendicular, PR, drawn at the point of incidence, is called the angle of incidence. The angle of reflection, r, is that between this perpendicular, PR, and the direction PQ. If OP represent the magnitude and direction of the incident force, it may be resolved into OR and RP. But the reaction, PR, is equal to the vertical portion, RP, of the incident force, while the horizontal portion is not checked. Hence $PQ = OP$, and the angle of incidence is equal to the angle of *reflection.*

FIG. 15.



Reflected Motion.

Energy.

Energy is the power of doing work, *i. e.*, of overcoming any kind of resistance. It is in general a power put into a body by means of work, and which comes out of it when it does work, as in a wound-up clock, a red-hot iron, etc. The difference between energy and momentum is easily illustrated. When a bullet is fired from a rifle, the momenta of both are equal, but the energy of the former, *i. e.*, its power of doing work, as piercing a board, is far greater. Energy is proportional to the square of the velocity of the moving body. Thus, a cannon-ball given double speed will penetrate four times as far into a wall; and a stone thrown upward at the rate of ninety-six feet per second will rise nine times as far as with a velocity of thirty-two feet.

Two Forms of Energy.

Energy may be either active or latent. When a rock is tumbling down a mountain-side, it exhibits the force of gravity in full sway; but when the rock was lodged on the mountain-top, it possessed the same energy, which could be developed at any moment by loosening it from its place. These two forms are known as energy of motion and energy of position, or kinetic and potential energy. The following may be taken as examples to show the difference between kinetic and potential energy. We wind a watch, and by a few moments of labor condense in the spring a potential energy, which is doled out for twenty-four hours in the kinetic energy of the moving wheels and hands. Lift a pendulum, and you thereby give the weight potential energy. Let it fall, and the potential changes gradually to kinetic. At the center of the arc the potential is gone and kinetic is possessed. Then the kinetic changes again to potential, which increases till the end of the arc is reached and the pendulum ceases to rise, when the energy is that of position, not of motion. Potential energy is like what is concealed, lying in wait and ready to burst forth on the instant. It is that of a loaded gun prepared for the arm of the marksman. It is that of a river trembling on the brink of a precipice, about to take the fearful leap. It is that of a weight wound up and held against the tug of gravity. It is that of the engine on the track with the steam hissing from every crevice. On the contrary, kinetic *energy is that in actual* operation. The bullet is speeding to the

mark; the river is tumbling; the weight is falling; the engine is flying over the rails. It is that of heat radiating from our fires; electricity carrying our messages over the continent; and gravity drawing bodies headlong to the earth.

Conservation of Energy.

The sum of all the energy in the universe remains the same while its transformations are infinite. One kind of energy is changed into another; from an available form to one that is not controllable. A hammer falls by the force of gravity. In coming to rest when stopped, it does the work of crushing what it hits, and its motion as a mass is converted into one of molecules, revealing itself to our touch as heat. The sun is continually sending forth radiant energy, which has been stored up in it by the aggregation of matter during untold ages. Its kinetic energy is thus becoming dissipated into potential energy; but, even after it ceases to glow, the grand total, including all that was once kinetic, will remain unchanged.

Faraday, the great English physicist, pronounced the law of the Conservation of Energy "the grandest ever presented for the contemplation of the human mind." It has been established within the present century; yet we now know that former scholars had inklings of the wonderful truth. It arose in connection with discoveries on the subject of Heat, and its history will be treated of hereafter.

CHAPTER III.

ATTRACTION.

"THE smallest dust which floats upon the wind
Bears this strong impress of the Eternal mind:
In mystery round it subtle forces roll,
And gravitation binds and guides the whole."

"Attraction, as gravitation, is the muscle and tendon of the universe, by which its mass is held together and its huge limbs are wielded. As cohesion and adhesion, it determines the multitude of physical features of its different parts. As chemical or interatomic action, it is the final source to which we trace all material changes."—ARNOTT.

MOLECULAR FORCES.

Attractive and Repellent Forces.

IF we take a piece of iron and attempt to pull it to pieces, we find that there is a force which holds the molecules together and resists our efforts. If we try to compress the metal, we find that there is a force which holds the molecules apart and resists our efforts as before. If, however, we apply heat, the iron expands and finally melts. So, also, if we heat a bit of ice, the attractive force is gradually overpowered, the solid becomes a liquid, and at last the repellent force predominates and the liquid passes off in vapor. In turn, we can cool the vapor, and convert it back successively into water and ice. We thus see that there are two opposing forces which reside in the molecules—an attractive and a repellent force, and that the latter is heat. There are three kinds of the former, cohesion, adhesion, and chemical affinity.

Cohesion.

Cohesion is that force which holds together molecules of the same kind.

Matter occurs in three states—solid, liquid, and gaseous. *These depend on the* relation of the attractive and repellent

forces, cohesion and heat. If they are nearly balanced, so that the attractive force is slightly in excess, the body is liquid; if very greatly in excess, it is solid; if the repellent force be much in excess, the body is gaseous. There are in nature all gradations from the densest solid to the most tenuous gas. Many substances may be made to take the three states successively. Thus, by the application of heat, ice may be converted into water, and thence into vapor; or, vice versa, by the withdrawal of heat. Some solids pass easily to the liquid state, while others pass directly from solid to gas.

Three States of Matter.

Take two bullets, and having flattened and cleaned one side of each, press them together with a twisting motion. They will cohere when the molecules are crowded into apparent contact. Surfaces may appear to the eye to be in contact when they are not actually so. Newton found, during some experiments on light, that a convex lens or a watch-glass laid on a flat glass does not touch it, and can not be made to do so, even by a force of many pounds.

Cohesion Acts at Insensible Distances.

If two globules of mercury be brought near each other, at the instant they seem to touch they will suddenly coalesce.—Two freshly-cut surfaces of rubber, when warmed and pressed together, will cohere as if they formed one piece.—The process of welding illustrates this principle. A wrought-iron tool being broken, we wish to mend it. So we bring the iron to a white heat at the ends which we intend to unite. This partly overcomes the attraction of cohesion, and the molecules will move easily upon one another. Laying now one of the two heated ends upon the other, we pound them until the molecules are brought near enough for cohesion to grasp them.

Within a liquid each molecule is pressed by the weight of all those above it, so that the slight cohesion between it and its neighbors is masked. At the surface there is no such liquid pressure. Cohesion causes the surface film to be in a state of tension like a sheet of stretched India rubber. A double film may be detached by using soapy water and lifting out of it the bowl of a pipe. The elasticity and toughness of the film are shown by

Surface Tension of Liquids.

blowing it into a bubble, whose surface is many times greater than that across the bowl that held it. A candle flame may be blown out by the bubble as it contracts toward its own center and expels a breeze of air through the tube of the pipe. There are many charming experiments that can be made with soap films.* A good recipe for making soap solution is as follows: Procure some of the best white Castile, or palm-oil soap. Scrape from it about four ounces of thin shavings, put these into a quart bottle of purest rain-water, or distilled water, and shake until the strongest clear solution of the soap is had. Then add a pint of pure concentrated glycerine. A film from this mixture will last for hours, and bubbles over a foot in diameter are easily made.

Liquids Tend to Form Spheres.

Mix alcohol and water in such proportion that a drop of olive-oil will sink into it without going to the bottom. The action of gravity on it is just balanced by the buoyancy of the liquid, so that cohesion can act without much interference. Like a soap-bubble, the outside film of the oil tends to contract upon its interior, and a nearly perfect sphere remains suspended. The contraction of the tough surface film is what produces the roundness of dew-drops, rain-drops, globules of mercury, and melted lead as it falls and cools into round shot.

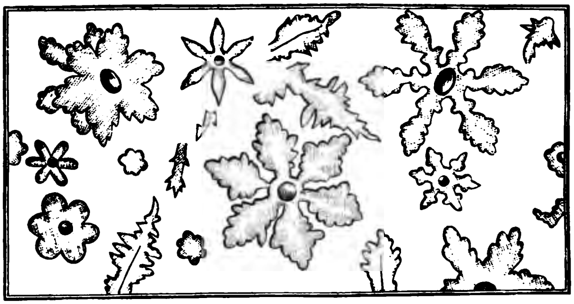
Solids Tend to Form Crystals.

When a liquid becomes a solid, the general tendency is to assume a symmetrical form. For each kind of crystallizable matter there is a tendency toward the assumption of a special shape and angle by which its crystals may be recognized. Epsom salt crystallizes in four-sided prisms, common salt in cubes, and alum in octahedra. We can illustrate the formation of the last by adding alum to hot water until no more will dissolve. Then suspend strings across the dish and set it away to cool. Beautiful octahedral crystals will collect on the threads and sides of the vessel. The slower the process, the larger the crystals. When different substances are contained in the same solution, they separate on crystallization, and each molecule goes to its own.

* See *Popular Science Monthly*, Vol. IX., p. 575; *Scientific American*, May 15, 1886; *Scientific American Supplement*, January 25, 1879.

The exquisite beauty of these crystalline forms is seen in snow-flakes and the frost-work traced on a cold morning upon the windows or the stone-flagging. A beam of light passed through a block of ice reveals these crystals as a mass of star-like flowers (Fig. 16). It is noticeable that, as the crystals melt, at the center of each liquid flower is a vacuum, showing that there is

FIG. 16.



Ice Flowers.

not enough water formed to fill the space occupied by the crystal, and that the solid contracts as it passes into a fluid. This experiment is easily tried. The ice must be cut parallel to the plane of its freezing and be not over half an inch thick. A common oil lamp will furnish the light.

Melted iron rapidly cooled in a mold has not time to arrange its crystals. If, however, the iron be afterward violently jarred, as when used for cannon, rail-cars, etc., the molecules take on the crystalline form and the metal becomes brittle. On examining such a piece of iron, which can easily be procured at a car or machine shop, we can see in a fresh fracture the smooth, shining face of the crystals.

Annealing and Tempering.

If a piece of wrought-iron be heated and then plunged into water, it becomes hard and brittle. If, on the contrary, it be heated and cooled slowly, it is made tough and flexible. Steel is tempered by heating white-hot, then cooling quickly, and afterward re-heating and cooling slowly. It becomes then one of the most *elastic and tough* of known substances.

The Rupert's Drop.

The Rupert's drop is a tear of melted glass dropped into water, and cooled quickly. The exterior at once becomes rigid, while the interior is still hot and expanded. When the whole mass is cool, the interior is in a state of strain. If the tail of the drop be nipped off, so that the exterior shell is broken, the tension will cause the mass to fly into powder with a sharp explosion. All glassware, when first made, is brittle, but it is annealed by being drawn slowly through a long oven, highly heated at one end, but quite cool at the other. During this passage, the molecules of glass have time to arrange themselves in a stable position.

FIG. 17.

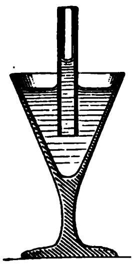
Rupert's Drop.

The restoration of cohesion is beautifully seen in the gilding of china. A figure is drawn upon the china with a mixture of oxide of gold and an essential oil. The article is then heated, whereby the essential oil and the oxygen of the gold are expelled, and a red-brown pattern remains. This consists of pure gold in a finely-divided state, without luster. By rubbing with a hard burnisher, the particles of gold cohere and reflect the rich yellow color of the polished metal.

Adhesion.

Adhesion is the force which holds together molecules of different kinds. Two pieces of wood are fastened together with glue, two pieces of china with cement, two bricks with mortar, two sheets of paper with mucilage, and two pieces of tin with solder.—Syrup and coal-oil are purified by filtering through animal charcoal.—Bubbles can be blown from soap-suds, because the soap by its adhesive force holds together the particles of water.

FIG. 18.



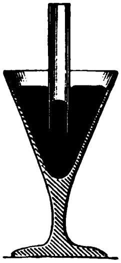
Direct Capillarity.

Capillarity.

If there is strong adhesion between a liquid and a solid partly immersed in it, the liquid rises above the general level and wets the solid, causing the surface film along the line of contact to be concave upward. This is shown in Fig. 18, which represents a tube of *glass dipped in water.* On the inner side of the tube the con-

cavity is more marked in proportion as the bore is less. By the contraction of the surface film, the water is drawn up the tube. This is called capillarity (*capillus*, a hair), because best shown in the finest tubes like hairs.

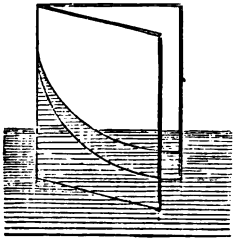
Fig. 19.



Reversed Capillarity.

If the tube be thrust into a liquid, like mercury, which does not wet it, the capillarity is reversed; the liquid is convex upward, and within the tube it is depressed.

Fig. 20.



The Capillary Curve.

A striking illustration of the effect of narrowing the exposed surface of the film may be seen by putting two clean glass plates edgewise into colored water so that their lower part shall be immersed, with a pair of upright edges touching (Fig. 20). Just at the edge the liquid rises to the top; the height decreases as the successive distances between the two plates increase, and the liquid surface seen edgewise forms a curve called the Hyperbola.

Law of Capillarity. The height to which a liquid rises in a wetted tube varies inversely as the diameter. In a tube whose inner diameter is 1 mm., water rises at ordinary temperature (62° F.) to a height of 29 mm. (a little over an inch); if the tube be only ½ mm. in diameter, the height will be twice as great. Cold water rises higher than warm water, or than alcohol or ether.

Imbibition. Many porous bodies (*sensible* pores), such as sugar, blotting-paper, sand, a lamp wick, a towel, absorb liquids at a rate which is increased if the materials be warm. In the same way, water is drawn to the surface of the ground to furnish vegetation with the materials of growth. Even in the winter, when the surface is frozen, the water still finds its way upward, and freezes into ice, which in the spring produces mud, although there may have been little rain or snow.

Since there is no free surface, this is not capillarity. Ropes *absorb water by imbibition*, swell, and shrink often to breaking.

In 1586 the Egyptian obelisk, weighing a million pounds, was to be raised in the square of St. Peter's, Rome. Pope Sixtus V. proclaimed that no one should utter a word aloud until the engineer announced that all danger had passed. As the majestic column ascended, all eyes watched it with wonder and awe. Slowly it arose, inch by inch, foot by foot, until the task was almost completed, when the strain became too great. The huge ropes yielded and slipped. The workmen were dismayed, and fled wildly to escape the impending mass of stone. Suddenly a voice broke the silence. "*Wet the ropes,*" rang out, clear-toned as a trumpet. The crowd looked. There, on a high post, standing on tiptoe, his eyes glittering with the intensity of excitement, was one of the eight hundred workmen, a sailor named Bresca di S. Remo. His voice and appearance startled every one; but his words inspired. He was obeyed. The ropes swelled and bit the stone. The column ascended again, and in due time stood securely on its pedestal. The daring sailor was not only forgiven, but his descendants to this day enjoy the reward of providing the palm-branches used on Palm Sunday at St. Peter's.

Solution.

Sugar will dissolve in water, because the adhesion between the two substances is stronger than the cohesion of the sugar. This contest between adhesion and cohesion is seen when we let a drop of oil fall on water. Adhesion tends to draw the oil to the liquid, so as to mix thoroughly, and cohesion to prevent this. The extent to which the drop will spread will depend on the relation of the two attractions, and vary for every substance. Thus each oil has its own cohesion figure, which enables the chemist to detect readily differences in mixtures. Dissolve a little salt in a glass of water, and touch the surface of the liquid with a pen full of ink. The characteristic figures will quickly appear.—Dissolve in water a pinch of salt and a lump of loaf-sugar. Touch the surface with lunar caustic. The figure of nitrate of silver will be seen.

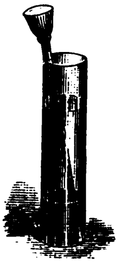
As heat weakens cohesion, it hastens solution, so that a substance generally dissolves more rapidly in hot water than in cold. In like manner, pulverizing a solid aids solution. Liquids also absorb gases by adhesion. Thus water contains air, which renders it pleasant to the taste. As pressure and cold weaken

the repellent force, they favor the adhesion between the molecules of a gas and water. Soda-water receives its effervescence and pungent taste from carbonic-acid gas, which, being absorbed under great pressure, escapes in sparkling bubbles when the pressure is removed.

Diffusion of Liquids.

Let a jar be partly filled with water colored by blue litmus. Then, by a funnel-tube, pour clear water containing sulphuric acid to the bottom, beneath the colored water. At first, the two will be distinctly defined, but in a few days they will mix, as will be seen by the change of color from blue to red. A drop of sulphuric acid may thus be distributed through a quart of water. Most liquids will mingle when brought in contact. If, however, there is no adhesion between their molecules, they will not mix, and will separate even after having been thoroughly shaken together. For example, shake together mercury, water, and sweet oil; they will soon separate and settle in layers with the oil at the top and the mercury at the bottom. Diffusion is a slow process, so we generally help it by shaking or stirring the mixture of liquids. A story is told of some negroes in the West Indies who supplied themselves with liquor by inverting the neck of a bottle of water in the bunghole of a cask of rum. The water sank into the barrel, while the rum rose to take its place. Water and rum diffuse readily, but rum is lighter and requires time to diffuse to the bottom.

FIG. 21.



Diffusion of Liquids.

FIG. 22.

Diffusion of Gases.

Diffusion of Gases.

Hydrogen gas is only $\frac{1}{14}$ as heavy as common air. Yet, if two bottles be arranged as in Fig. 22, the lower one filled with the heavy gas, and the upper with the lighter, the gases will soon be uniformly mixed. This illustrates the diffusion of gases.

This phenomenon is explained by the theory that the molecules of all bodies are in rapid motion. As the worlds in space are clustered in mighty systems, the members of each revolving about one another in inconceivably vast orbits, so each

body is a miniature system, its molecules moving in inconceivably minute paths. In a gas, the molecular velocity is enormous. The particles of ammonia gas, for example, are flying to and fro at the rate of twenty miles per minute. "Could we, by any means," says Prof. Cooke, "turn in one direction the actual motion of the molecules of what we call still air, it would become at once a wind blowing seventeen miles per minute, and exert a destructive power compared with which the most violent tornado is feeble."—Invert a bottle over a lighted candle, and the oxygen of the inclosed air being soon consumed the flame goes out. Instead of the bottle, use a foolscap-paper cone. There will be an interchange of gases through the pores of the paper, and the light will burn with moderate freedom.

Fig. 23.

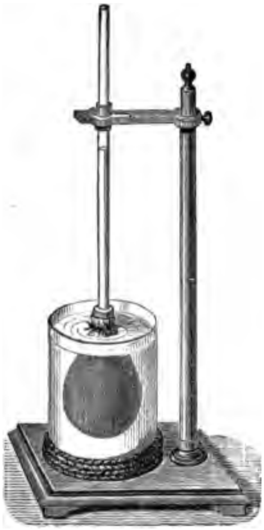
Graham's Diffusion Tube.

Diffusion of Gases is still more strikingly shown in the experiment of Fig. 23, devised by Prof. Graham. Fit a porous cup used in Grove's Battery with a cork and glass tube. Fasten the tube so that it will dip beneath the colored water in the glass. Then invert over the cup a jar of hydrogen. The gas will pass through the sensible pores of the earthenware and down the tube so rapidly, as almost instantly to bubble up through the water. Rose balloons lose their buoyancy, because the hydrogen escapes through the pores of the rubber. If they were filled with air and placed in a jar of hydrogen, that gas would creep in so rapidly as to burst them.—In performing the experiment shown in Fig. 23, coal-gas may be used. After the bubbling ceases, on withdrawing the jar water rises in the tube. The thin gas diffuses out into the denser air, producing a partial vacuum within.

When two liquids are separated by a thin substance, the interchange may be modified in a curious manner, according to *the nature of the liquid* and the substance used. At the end

of a glass tube (Fig. 24) fasten a bladder of alcohol. Fill the jar with water, and mark the height to which the alcohol ascends in the tube. The column will soon begin to rise slowly. On examination, we shall see that the alcohol is passing out through the pores of the bladder and mixing with the water, while the water is coming in more rapidly. The bladder is not porous in the sense of having sensible pores.

FIG. 24.



Osmosis.

Diffusion of fluids, through the medium of a substance which attracts them unequally, is called osmosis. It is applied by the chemist in methods of analysis where the separation of substances is based on their unequal diffusibility. Crystals in solution pass readily through animal membrane, like bladder, while substances that do not crystallize, like gum, gelatine, or white of egg, are stopped.

ATTRACTION OF GRAVITATION.

We have spoken of the attraction existing between the molecules of bodies at minute distances. We now notice an attraction which acts at all distances.

Law of Gravitation.

Hold a stone in the hand, and you feel a power constantly drawing it to the ground. We call this familiar phenomenon weight. It is really the attraction of the earth pulling the stone back to itself—an instance of a general law, one operation of an ever-active force. For every particle of matter in the universe attracts every other particle with a force proportional to the product of their masses, and increasing as the square of the distance decreases.

The force of gravitation acts on every particle of matter, and hence it is not confined to our own world. By its action *the heavenly bodies* are bound to one another, and thus kept in

their orbits. It may help us to conceive how the earth is supported, if we imagine the sun letting down a huge cable, and every star in the heavens a tiny thread, to hold our globe in its place, while it in turn sends back a cable to the sun and a thread to every one of the stars. So we are bound to them and they to us. Thus the worlds throughout space are linked together by these cords of mutual attraction, which, interweaving in every direction, make the universe a unit.

Gravitation.

Gravitation is the general term applied to the attraction that exists between all bodies in the universe. Gravity is the earth's attraction for terrestrial bodies; it tends to draw them toward the center of the earth.

The latter part of the sixteenth century witnessed the establishment of the principles of falling bodies. Galileo, while sitting in the cathedral at Pisa and watching the swinging of an immense chandelier which hung from its lofty ceiling, noticed that its vibrations were isochronous. This was the germ-thought of the pendulum and the clock. Up to his time it had been taught that a 4-lb. weight would fall twice as fast as a 2-lb. one. He proved the fallacy of this view by dropping from the Leaning Tower of Pisa balls of different metals—gold, copper, and lead. They all reached the ground at nearly the same moment. The slight variation he correctly accounted for by the resistance of the air, which was not the same for all.

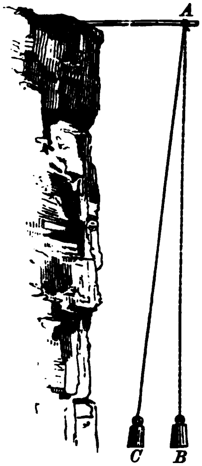
Newton and his immediate predecessors knew the law of terrestrial gravity as manifested in falling bodies. When quite a young man, Newton entertained the idea that the attraction which draws bodies downward at the earth's surface must exist also between masses widely separated in space, such as the earth and the moon. To test this, he calculated how far the moon bends from a straight line, *i. e.*, falls toward the earth every second. Knowing the distance a body falls in a second at the surface of the earth, he endeavored to see how far it would fall at the distance of the moon. For years he toiled over this problem, but an erroneous estimate of the earth's diameter then accepted by physicists prevented his obtaining a correct result. Finally, *a more accurate* measurement having been made, he *inserted this in his* calculations. Finding the result was likely

to verify his conjecture, his hand faltered with the excitement, and he was forced to ask a friend to complete the task. The truth was reached at last, and the grand law of gravitation discovered (1682).

Illustrations of Gravity.

A stone falls to the ground because the earth attracts it; but in turn the stone attracts the earth. Each moves to meet the other, but the stone passes through as much greater distance than the earth as its mass is less. The mass of the earth is so great that its motion is imperceptible.—A plumb-line hanging near a mountain is attracted from the vertical. In Fig. 25, AB represents the ordinary position of the line, while AC indicates the attractive power (greatly exaggerated) of the mountain. Maskelyne, in 1774, found the attraction of Mount Schehallien to deflect a plumb-line 12″. By comparing this force with that of the earth, the specific gravity of the earth was estimated to be five times that of water. Later investigations make it 5.67.

FIG. 25.



Deflection of a Plumb-line by a mountain. (Exaggerated.)

Mass and Weight.

The quantity of matter in a body is its mass. The measure of the earth's attraction upon it is its weight. If m be the number of units of mass in a body, and g be the number of units of force expressing the earth's attraction, then its weight, w, is equal to m multiplied by g; or, $w = mg$, whence

$$m = \frac{w}{g}.$$

The Earth's Center of Gravity.

The earth's center of gravity is that point within it where the attraction of all the particles on any one side is equal to the attraction of all those on the opposite side. As an attracting mass the whole earth may be regarded as if it were concentered at this point. Its position is probably very near the geometric center. When the earth's center is mentioned we generally *mean its center of gravity.*

The Center of Gravity of a Body.

The center of gravity of a body is that point about which it may be balanced. A straight line from this point to the earth's center of gravity is called the line of direction. It is also called a vertical, or plumb-line. Gravity tends to cause the body to move along this line toward the center. Downward means toward the earth's center; upward means the opposite. Any two bodies moving downward, one from America and the other from Europe, if unresisted, would meet at the earth's center if their fall were properly timed.

Laws of Weight.

The weight of a body at the center of the earth is nothing; for since the opposite attractions are mutually balanced there can be no tendency to motion in any direction.

The weight of a body above the surface of the earth decreases as the square of the distance from the center of the earth increases. A body at the surface of the earth (4,000 miles from the center) weighs 100 lbs. What would be its weight 1,000 miles above the surface (5,000 miles from the center)? SOLUTION: $(5{,}000 \text{ mi.})^2 : (4{,}000 \text{ mi.})^2 :: 100 \text{ lbs.} : x = 64$ lbs. Or, its weight would decrease in the ratio of $\frac{4000^2}{5000^2} = \frac{16}{25}$. Hence it would weigh $\frac{16}{25} \times 100$ lbs. $= 64$ lbs.—The weight of a body below the surface of the earth is commonly said to decrease directly as the distance from the center decreases. Thus, 1,000 miles below the surface, a body would lose $\frac{1}{4}$ its weight. In fact, however, the density of the earth increases so much toward the center, that "for $\frac{7}{10}$ of the distance the force of gravity actually becomes stronger than on the surface."

The weight of a body varies on different portions of the surface of the earth. It will be least at the equator, because, on account of the bulging form of our globe, a body is there farther from the earth's center; and the centrifugal force is there strongest. It will be greatest at the poles, because, on account of the flattening of the earth, a body at a pole is there nearer to the earth's center; there is no centrifugal force at the poles. In these statements concerning weight, a spring-balance *is supposed to* be employed. If it be graduated to *indicate correctly at a* medium latitude, it would show too little

at the equator, and too much at the poles. In other words, a pound weighed with such a spring-balance at the equator would contain a greater mass of matter than one weighed at the poles by about $\frac{1}{192}$ part.

Under the influence of the constant force of gravity alone, all bodies fall with equal rapidity.

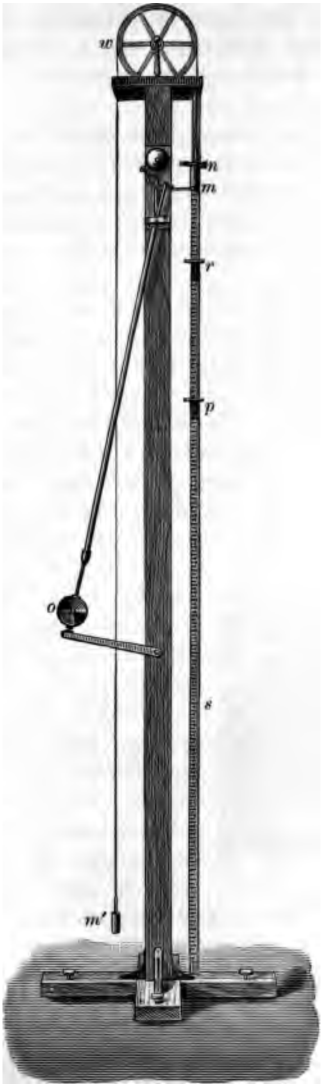
Falling Bodies. This is well illustrated by the "guinea and feather experiment." Let a coin and a feather be placed in a tube, and the air exhausted. Quickly invert the tube, and the two bodies will fall in nearly the same time. Let in the air again, and the feather will flutter down long after the coin has reached the bottom. The same fact may be noticed in the case of a sheet of paper. When spread out, it merely flutters to the ground; but when rolled in a compact mass, it falls quickly. In this case we have not increased the force of attraction, but we have diminished the resistance of the air. It is difficult for many to understand how, under the influence of gravity alone, all bodies fall with equal rapidity. An illustration, which is usually effective, is that of a number of bodies of the same kind, say bricks, which will separately fall in the same space of time. The reader will admit that, if all of them are connected together, inasmuch as nothing is thereby added to their weight, there is no reason why the mass of bricks should not fall in the time of a single one, notwithstanding it is a larger body.

FIG. 26.

Guinea and Feather Experiment.

Hence we conclude that in a vacuum all bodies descend with equal velocity, and that the resistance of the air and the adhesion of the feather to the tube are the *causes of the variation* we see between the falling of light and *of heavy bodies in it.*

FIG. 27.



Atwood's Machine.

Atwood's Machine.

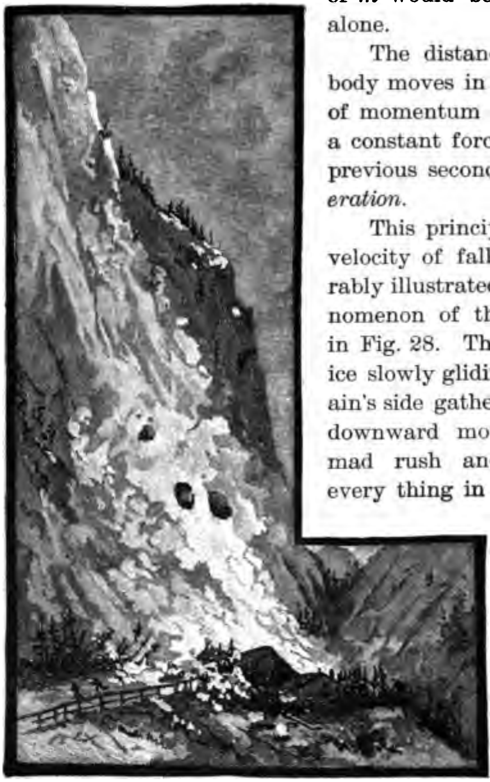
Fig. 27 represents a contrivance for measuring the rate of falling bodies, and is known as Atwood's machine. This consists of a very light grooved wheel, *w*, pivoted at the top of a firm vertical pillar, on one side of which is a graduated strip, *s*, divided into inches or centimeters. A silk thread, passing over the wheel, supports two equal masses, *m* and *m'*. The force of gravity on one of these just balances its force on the other. A small cross-bar, *n*, placed upon *m*, gives vertical motion, by the action of gravity on it, to the whole mass. The rate of motion is as much less than if it were falling freely as the mass of the cross-bar is less than the whole mass. An allowance has to be made for the mass of the wheel, which is put in circular motion at the same time. The cross-bar being thus made to fall slowly, the resistance of the air is decreased, and the distance of movement through each second is easily measured. A pendulum, *o*, marks the successive seconds, and is so arranged as to release the support at the proper moment, thus allowing the mass to move. Attached to the graduated strip are a movable ring, *r*, and a movable plate, *p*. If these be placed as

shown in Fig. 27, *m* would pass through the ring and be stopped by the plate, while the cross-bar would be caught upon the ring, so that any further motion of *m* would be due to momentum alone.

The distance through which a body moves in a second on account of momentum due to the action of a constant force upon it during the previous second, is called the *acceleration*.

This principle of the increasing velocity of falling bodies is admirably illustrated in the natural phenomenon of the avalanche shown in Fig. 28. The mass of snow and ice slowly gliding down the mountain's side gathers momentum in its downward movement till, with a mad rush and roar, it destroys every thing in its pathway.

FIG. 28.



An Avalanche.

If a body falls freely, the acceleration is about 9.8 meters, or 32 feet. The results of these, perhaps somewhat complicated experiments, may be stated substantially as follows: If a body be permitted to fall freely from a height, it will drop 16 feet the first second, and if uninfluenced by gravity would go 16 feet the next second, but it is really accelerated 32 feet, so that the distance traversed the second second is 48 ft. The distances for each second are shown in this table:

Bodies Falling Freely.

1st sec.	2d sec.	3d sec.	4th sec.	5th sec.	6th sec.
16 ft.	*48 ft.*	80 ft.	112 ft.	144 ft.	176 ft.

This law may be used to estimate roughly the depth of a well. Let a stone be dropped into the well, and the time noted before the sound of its striking the water or the bottom is audible. Suppose two seconds have elapsed. By reference to the table, it appears that in two seconds a falling body passes through 64 feet, which is, therefore, the approximate depth of the well. In this calculation, the time required for the sound to travel from the bottom of the well to the ear has been neglected. For short distances, sound may be regarded as instantaneously transmitted.

Of bodies thrown vertically into the air, the same law holds except that there is a *retardation* of 32 feet per second. Thus let the table indicate the distances traversed each second by a body projected upward at 112 feet per second.

1st sec.	2d sec.	3d sec.	4th sec.	5th sec.
112 ft.	80 ft.	48 ft.	16 ft.	– 16 ft.

It is evident from the table that, at the end of the fourth second, the body will reach a point of rest and then begin to descend, according to the table for a falling body. At the end of eight seconds, it will reach the ground again, with the *same velocity* (112 ft.) with which it was originally projected. It should be noted also (1) that, at any given height from the ground, the up and down velocities are the same, and (2) that the times occupied in the ascent and descent are exactly equal.

Resistance of Air to Moving Bodies.

A body in falling or otherwise moving through the air expends energy in overcoming the resistance of the air. The flight of a cannon-ball is never so great as it would be if shot through a vacuum. Practically it is not easy to calculate beforehand the amount of energy to be lost through resistances.

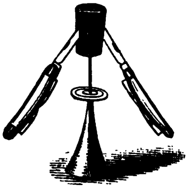
Equilibrium.

When a body is at rest the forces which act on every molecule in it are said to balance one another, or to be in equilibrium. The most important of these forces is gravity.

The three states of equilibrium are, stable, unstable, and indifferent. A body is in stable equilibrium when the center of gravity (page 39) is below the point of support, or when any movement *tends to raise* the center of gravity. In Fig. 29, th *cork and two knives* together form a connected body whos

center of gravity is outside, just beneath the needle. By pushing either knife a few oscillations are produced, but a position of rest is soon recovered. Any movement of the toy shown in Fig. 30 tends to raise the center of gravity, and it returns quickly to a state of rest.

FIG. 29



Stable Equilibrium.

A body is said to be in unstable equilibrium when the center of gravity is above the point of support, or when any movement tends to lower the center of gravity. If we take the cork as arranged with the knives in Fig. 29, and invert it, we shall have difficulty in balancing the needle; and, if we succeed, it will readily topple off, as the least motion tends to lower the center of gravity.

A body is said to be in indifferent equilibrium when the center of gravity is at the point of support, or when any movement tends neither to elevate nor lower the center of gravity. A ball of uniform density on a level surface will rest in any position, because the center of gravity moves in a line parallel to the floor. The center of gravity tends to seek the lowest point.

FIG. 30.

Stable Equilibrium.

A body will not tip over while the line of direction falls within the base, but will as soon as it falls without. The Leaning Tower of Pisa, in Italy (Fig. 31), beautifully illustrates this principle. It is about 188 feet high, and its top leans 15 feet, yet the line of direction falls so far within the base that it is perfectly stable, having stood for seven centuries. The feeling experienced by a person who for the first time looks down from the lower side of the top of this apparently impending structure is startling indeed.

In general, narrowness of base combined with height of *center of gravity*, tends to instability; breadth of base and *lowness of center of* gravity, produce stability.

"This is shown by the difficulty in learning to walk upon stilts. The art of balancing one's self may, however, be acquired by practice, as is seen in the Landes of south-western France. During a portion of the year these sandy plains are half covered with water, and in the remainder are still very bad walking. The natives accordingly double the

Fig. 31.

Leaning Tower of Pisa.

Fig. 32.

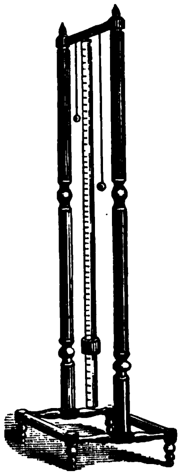
Walking on Stilts.

length of their legs by stilts. Mounted on these wooden poles, which are put on and off as regularly as the other parts of their dress, they appear to strangers as a new and extraordinary race, marching with steps of six feet in length, and with the speed of a trotting-horse. While watching their flocks, they suppo themselves by a third staff behind, and then with their rou *sheep-skin cloaks* and caps, like thatched roofs, seem to

little watch-towers, or singular lofty tripods, scattered over the country."—ARNOTT.

Our feet and the space between them form the base on which we stand. By turning our toes outward, we increase its breadth. When we stand on one foot, we bend over so as to bring the line of direction within this narrower base. When we walk, we incline to the right and the left alternately. When we walk up hill we lean forward, and in going down hill we incline backward, in unconscious obedience to the laws of gravity. We bend forward when we wish to rise from a chair, in order to bring the center of gravity over our feet. In walking we lean forward, so as to bring the center of gravity as far in front as possible. Thus, walking is a process of falling forward and then checking the fall. When we run, we lean farther forward, and so fall faster.

FIG. 33.



Pendulums.

The Pendulum.

The pendulum consists of a weight so suspended as to swing freely. Its movements to and fro are termed vibrations or oscillations. The path through which it passes is called the *arc*. The extent to which it goes in either direction from the lowest point is styled its amplitude. Vibrations performed in equal times are termed i-soch′ro-nous, (ἴσος, equal; χρόνος, time).

In the same pendulum, all vibrations of small amplitude are isochronous. If we let one of the balls represented in Fig. 33 swing through a short arc, and then through a longer one, on counting the number of oscillations per minute we shall find them very uniform.

The times of the vibrations of different pendulums are proportional to the square roots of their respective lengths. A pendulum $\frac{1}{9}$ the length of another, will vibrate three times as fast. A pendulum which vibrates seconds must be four times as long as one which vibrates half-seconds. The apparatus represented in Figs. 33 and 34 can be made by any carpenter or *ingenious pupil*, and will serve excellently to illustrate the

three laws of the pendulum. The law of the pendulum may be conveniently expressed in symbols. If t be the time of a single vibration in seconds, l the length of the pendulum, g the acceleration of gravity, l and g being expressed in feet, or in meters, and if π (3.14 +) be the ratio of the circumference to the diameter of a circle, then

$$\text{Time of vibration} = 3.14\sqrt{\frac{\text{Length of pendulum}}{32}}$$

This formula is convenient for use in solving problems. Conversely, the lengths of different pendulums are proportional to the squares of their times of vibration.

FIG. 34.

Pendulums of apparently the same length, but really different lengths.

The time of the vibration of the same pendulum will vary at different places, since it decreases as the square root of the number expressing the acceleration of gravity increases. At the equator a pendulum vibrates most slowly. The length of a seconds-pendulum at New York is about $39\frac{1}{10}$ inches.

The upper part of a pendulum tends to move faster than the lower part, and so hastens the speed. The lower part of a pendulum tends to move slower than the upper part, and so retards the speed. Between these extremes is a point which is neither quickened nor impeded by the rest, but moves in the same time that it would if it were a particle swinging by an imaginary line. This point is called the center of oscillation. It lies a little below the center of gravity. This determines the real length of a pendulum, which is the distance from the point of support to the center of oscillation. The imaginary pendulum above described is known in Physics as the *Simple Pendulum.*—39.1 inches = 993.3 mm.

In Fig. 34 is shown an apparatus containing pendulums of

different shapes, but of the same length. If they are started together, they will immediately diverge, no two vibrating in the same time. As pendulums, they are not of the same length.

The center of oscillation is found by trial. "Take a flat board of any form and drive a piece of wire through it near its edge, and allow it to hang in a vertical plane, holding the ends of the wire by the finger and thumb. Take a small bullet, fasten it to the end of a thread, and allow the thread to pass over the wire so that the bullet hangs close to the board. Move the hand by which you hold the wire horizontally in the plane of the board, and observe whether the board moves forward or backward with respect to the bullet. If it moves forward, lengthen the string; if backward, shorten it till the bullet and the board move together. Now mark the point of the board opposite the center of the bullet, and fasten the string to the wire. You will find that, if you hold the wire by the ends and move it in any manner, however sudden and irregular, in the plane of the board, the bullet will never quit the marked spot on the board. Hence this spot is called the center of oscillation, because, when the board is oscillating about the wire when fixed, it oscillates as if it consisted of a single particle placed at the spot. It is also called the center of percussion, because, if the board is at rest and the wire is suddenly moved horizontally, the board will at first begin to rotate about the spot as a center."—J. CLERK MAXWELL, on "Matter and Motion," p. 104.

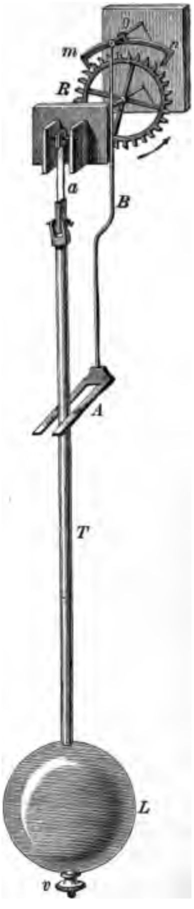
Huyghens discovered that the point of suspension and the center of oscillation are interchangeable. If, therefore, a pendulum be inverted, and a point found at which it will vibrate in the same time as before, this is the former center of oscillation; while the old point of suspension becomes the new center of oscillation. The center of oscillation is the same as the center of percussion. The latter is the point where we must strike a suspended body, if we wish it to revolve about its axis without any strain. If we do not hit a ball on the bat's center of percussion, our hands "sting" with the jar.

The Pendulum as a Time-keeper.

The friction at the point of suspension, and *the resistance of* the air, soon destroy the motion of the

pendulum. The clock is a machine for keeping up the vibration of the pendulum, and counting its beats. In Fig. 35, *R* is the scape-wheel driven by the force of the clock-weight or spring, and *mn* the escapement, moved by the forked arm, *AB*, so that only one cog of the wheel can pass at each double vibration of the pendulum. Thus the oscillations are counted by the cogs on the wheel, while the friction and the resistance of the air are overcome by the action of the weight or spring. The action of a clock is clearly seen by procuring the works of an old clock and watching the movements of the various parts. As "heat expands and cold contracts," a pendulum lengthens in summer and shortens in winter. A clock, therefore, tends to lose time in summer and gain in winter. To regulate a clock, we raise or lower the pendulum-bob, *L*, by the nut *v*.

Fig. 35.



Clock Pendulum.

The sun-dial was doubtless the earliest device for keeping time. The clepsydra was afterward employed. This consisted of a vessel containing water, which slowly escaped into a dish below, in which was a float that by its height indicated the lapse of time. King Alfred used candles of a uniform size, six of which lasted a day. The first clock erected in England, about 1288, was considered of so much importance that a high official was appointed to take charge of it. The clocks of the middle ages were extremely elaborate. They indicated the motions of the heavenly bodies; birds came out and sang songs, cocks crowed, and trumpeters blew their horns; chimes of bells were sounded, and processions of dignitaries and military officers, in fantastic dress, marched in front of the dial and gravely announced the time of day.

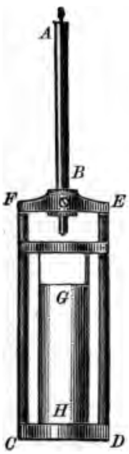
Watches were made at Nuremberg in the fifteenth century. They were styled Nuremberg eggs. Many were as small as the watches of the present day, while others were as large as a dessert-plate. They had no minute or second hand, and required winding twice a day.

Compensation Pendulums.

Compensation pendulums are made by using two metals in such a way that the expansion of one part downward may be exactly counteracted by the upward expansion of the other part, thus making the effective length of the pendulum always the same.

One of the most common forms is shown in Fig. 36. It is constructed as follows: The pendulum-rod, *AB*, supports a glass jar partly filled with mercury, inclosed in the steel frame-work, *FCDE*. When the weather is warm, the rod and frame-work expand, and thus increase the length of the pendulum. But at the same time the mercury in the glass jar expands and rises, so that by a proper adjustment the center of oscillation is carried as far upward by the expansion of the mercury as downward by the expansion of the rod and frame-work. The distance between the centers of suspension and oscillation remaining the same, the vibrations of the pendulum continue unaltered.

Fig. 36.



Compensation Pendulum.

In another form of the compensating pendulum, the ball is supported by a frame-work composed of rods of different metals, so adjusted that the downward expansion of one part is exactly compensated by the upward expansion of the other part.

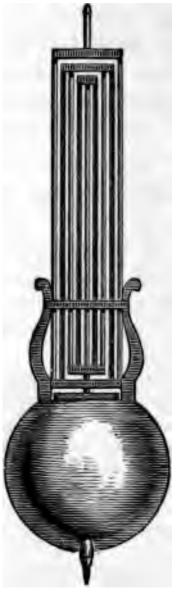
In the form shown in Fig. 37, called the gridiron pendulum, there are five steel bars expanding downward and four brass bars expanding upward. As the relative expansibility of brass compared with steel is as 100 to 61, the length of the steel bars is $\frac{100}{61}$ that of the brass.

Length of the Seconds-pendulum.

The length of the pendulum vibrating seconds has been very accurately determined. At the ne place it is invariable, but it varies with the latitude. At

the equator it is 39.0217 inches; at New York, 39.10237 inches; at Spitzbergen, 39.21614 inches. The cause of this variation is the difference in the force of gravity in different places, due to the spheroidal shape of the earth.

Fig. 37.



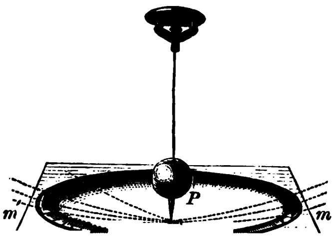
Gridiron Pendulum.

The polar diameter of the earth being twenty-six miles shorter than the equatorial diameter, any point on the surface of the earth near either pole is nearer the center, and the force of terrestrial gravity is stronger than at points on or near the equator. Consequently, a pendulum which vibrates seconds at the equator, on being carried to a latitude of 40° to 50°, is more strongly acted upon by gravity, and vibrates more rapidly. In order, therefore, that it may continue to make exactly one vibration in each second, the rapidity of vibration must be diminished by increasing the length of the pendulum.

Other Uses of the Pendulum.

Since the time of vibration of a pendulum indicates the force of gravity, and the force of gravity decreases as the square of the distance from the center of the earth increases, we may thus find the semi-diameter of the earth at various places, and ascertain the figure of our globe. Knowing the force of gravity at any point, the velocity of a falling body can be determined. The pendulum may be used as a standard of measures. Foucault devised a method of showing the rotation of the earth on *its axis, founded* upon the fact that the pendulum vibrates *constantly in one plane.* A pendulum 220 feet in length was

Fig. 38.



Foucault's Method.

suspended from the dome of the Pantheon in Paris. The lower end of the pendulum traced its vibrations north and south upon a table beneath, sprinkled with fine sand. These paths did not coincide, but at each return to the outside, the pendulum marked a point to the right. At the poles of the earth the pendulum, constantly vibrating in the same vertical plane, would perform a complete revolution in twenty-four hours, making thus a kind of clock. At the equator it would not change east or west, as the plane of vibration would go forward with the diurnal rotation of the earth. The shifting of the plane would increase as the pendulum was carried north or south from the equator.

By observing the difference in the length of a seconds-pendulum at the top of a mountain and at the level of the sea, the density of the earth may be estimated.

CHAPTER IV.

ELEMENTS OF MACHINES.

NATURE is a reservoir of power. Tremendous forces are all about us but they are not adapted to our use. We need to remold the energy to fit our wants. A water-fall can not grind corn nor the wind draw water. Yet a machine will gather up these wasted forces, and turn a grist-mill or work a pump. A kettle of boiling water has little of promise; but husband its energy in the steam-engine, and it will weave cloth, forge an anchor, or bear our burdens along the iron track.

"The hero in the fairy tale had a servant who could eat granite rocks, another who could hear the grass grow, and a third who could run a hundred leagues in half an hour. So man in nature is surrounded by a gang of friendly giants who can accept harder stints than these. There is no porter like gravitation, who will bring down any weight you can not carry, and if he wants aid, knows how to get it from his fellow-laborers. Water sets his irresistible shoulder to your mill, or to your ship, or transports vast bowlders of rock, neatly packed in his iceberg, a thousand miles."

EMERSON.

The Simple Machines.

THE simple machines are the elements to which all machinery can be reduced. The watch with its complex system of wheel-work, and the engine with its belts, cranks, and pistons, are only various modifications of some of the six elementary forms—the lever, the wheel and axle, the inclined plane, the screw, the wedge, and the pulley. These six may be still further reduced to two—the lever and the inclined plane.

They are often termed the Mechanical Powers, but they do not produce work; they are only the means of applying it. Here again the doctrine of the Conservation of Energy holds good. The work done by the power is always equal to the resistance overcome in the weight.

The law of mechanics is, *the power multiplied by the distance through which it moves, is equal to the weight multiplied by the distance through which it moves.* 1 lb. of powe

moving through 10 feet = 10 lbs. of weight moving through one foot, or vice versa. In theory, the parts of a machine have no weight, move with no friction, and meet no resistance from the air. In practice, these influences must be considered.

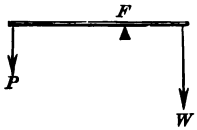
The Law of Mechanics.

The Lever.

The lever is a bar turning on a pivot. The force used is termed the power (P), the object to be lifted the weight (W), the pivot on which the lever turns the fulcrum (F), and the parts of the lever each side of the fulcrum the arms.

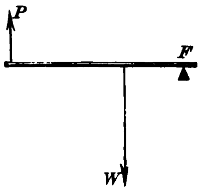
There are three classes of levers in which the fulcrum,

Fig. 39.



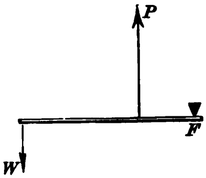
First Class.

Fig. 40.



Second Class.

Fig. 41.

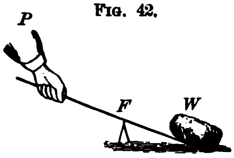


Third Class.

weight, and power are each respectively between the other two, as may be seen by comparing Figs. 39–41.

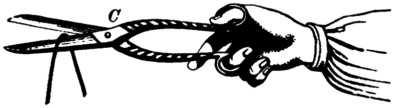
We wish to lift a heavy stone. Accordingly we put one

Fig. 42.



Lifting a Stone.

Fig. 43.



Cutting a String.

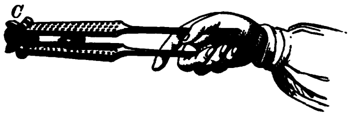
First Class.

end of a handspike under it, and resting the bar on a block at F, bear down at P.—A pump-handle is a lever of the first class. The hand is the P, the water lifted the W, and the pivot the F.—A pair of scissors is a double lever of the same class. The string to be cut the W, the hand the P, and the rivet the F.

We may also raise the stone by resting one end of the lever on the ground, which acts as a fulcrum, and lifting up on the bar.—An oar is a lever of the second class. The hand is the *P*, the boat the *W*, and the water the *F*. In this case the *F* is not immovable.

Second Class.

FIG. 44.



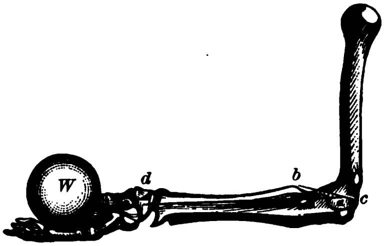
The ordinary nut-cracker is an example of levers of the second class. The fulcrum is at *C* (Fig. 44); the power is the hand, and the resistance is the nut to be cracked.

The treadle of a sewing-machine is a lever of the third class. The front end resting on the ground is the *F*, the foot is the *P*, and the force is transmitted by a rod to the *W*, the arm above.

Third Class.

The limbs of animals are examples of levers of the third class. The figure shows how the human arm acts as a lever.

FIG. 45.



The socket of the bone *a* is the fulcrum; a strong muscle, *bc*, attached near the socket, is the power; and the weight of the limb and whatever resistance *W* may oppose to motion is the weight. The forearm and hand are raised through a space of one foot by the contraction of a muscle applied near the elbow, moving through less than $\frac{1}{12}$ that space. The muscle, therefore, exerts 12 times the force with which the hand moves.

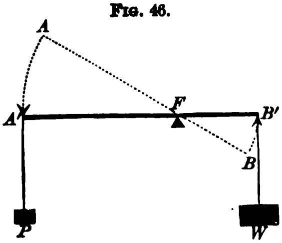
The product of *P* multiplied by the perpendicular distance between its line of action and *F*, is called the *moment* of *P*. In the lever, *P* balances *W* when the moments about the fulcrum are equal.

Law of Equilibrium.

In Fig. 46, assume *AB* to be the initial position of a lever, which is then turned into the position *A'B'* by application of the power, *P*, which balances the weight W, its line of action

being $A'P$, while that of W is $B'W$. The power moves through a distance equal to AA', while the weight moves through a distance equal to BB'. But these distances are proportional to $A'F$ and $B'F$. We may represent $A'F$ by Pd, the distance of the power's line of action from F; and $B'F$ by Wd, the distance of the weight's line of action from F.

FIG. 46.



If the weight P equal 3 lbs., and the length of power-arm $A'F$ be 4 ft.; and the weight W equal 6 lbs., and the length of the weight-arm FB' be 2 ft.,

$$4 \times 3 = 2 \times 6,$$

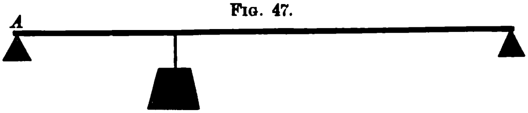
i. e., the product of the weight and weight-arm equals product of power and power-arm.

In the first and second classes, as ordinarily used, we gain power and lose time; in the third class we lose power and gain time.

Weight between two Supports.

If a weight is attached to a beam or pole which rests upon two supports, the beam acts as a lever of the second class, and the part carried by either support may be found by considering it as the power, and the other support as the fulcrum. If the weight rests on the middle of the beam, it is obvious that each support will bear half the burden. If, as shown in Fig. 47, the load is

FIG. 47.



Weight between Two Supports.

one third the length of the beam from A, the support, A, will bear two thirds of the weight, and the other support, one third.

Compound Levers.

When a small force is required to sustain a considerable weight, and it is not convenient to use a very long lever, a combination of levers, or a *compound* lever, is employed. When such a system

is in equilibrium, the power, multiplied by the continued product of the alternate arms of the levers, commencing from the power, is equal to the weight multiplied by the continued product of the alternate arms, commencing from the weight.

FIG. 48.

The Balance.

If the long arms are 6, 4, and 5 feet, and each of the shor arms 1 foot, then 1 pound at A will sustain 120 pounds at D.

Balance.

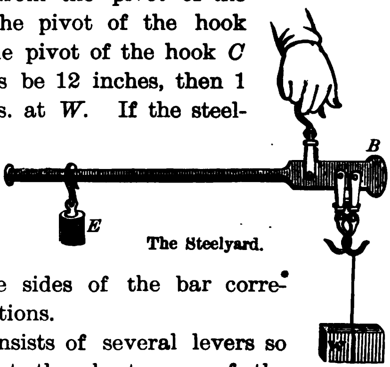
The balance is a lever of the first class with equal arms. The bar, AB (Fig. 48), has a *pair of scale-pans* suspended from its ends. At *the middle an axis, n,* made of steel and provided with

knife edge, rests upon a hard surface, so that the friction may be the least possible; this is the fulcrum.

Steelyard.

The steelyard is a lever of the first class. The *P* is at *E*, the *F* at *C*, and the *W* at *D*. If the distance from the pivot of the hook *D* to the pivot of the hook *C* be one inch, and from the pivot of the hook *C* to the notch where *E* hangs be 12 inches, then 1 lb. at *E* will balance 12 lbs. at *W*. If the steelyard be reversed (Fig. 50), then the distance of the *F* from the *W* is only ¼ as great, and 1 lb. at *E* will balance 48 lbs. at *D*. Two sets of notches on opposite sides of the bar correspond to these different positions.

Fig. 49.

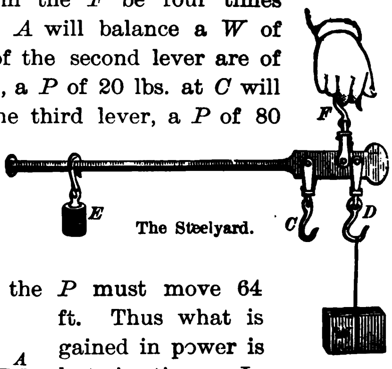


The Steelyard.

Compound Lever.

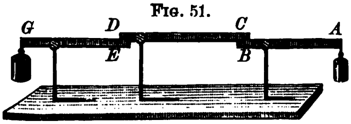
The compound lever consists of several levers so connected that the short arm of the first acts on the long arm of the second, and so on to the last of the series. If the distance of *A* (Fig. 51) from the *F* be four times that of *B*, a *P* of 5 lbs. at *A* will balance a *W* of 20 lbs. at *B*. If the arms of the second lever are of the same comparative length, a *P* of 20 lbs. at *C* will balance 80 lbs. at *E*. In the third lever, a *P* of 80 lbs. at *D* will balance 320 lbs. at *G*. With this system of three levers, 5 lbs. at *A* will accordingly balance 320 lbs. at *G*. To raise the *W* 1 ft., however, the *P* must move 64 ft. Thus what is gained in power is lost in time. In the application of power by means of levers of this class, there is no creation of force; on the contrary, there is an *appreciable loss of force* because of friction.

Fig. 50.



The Steelyard.

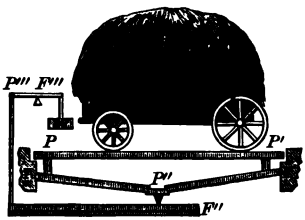
Fig. 51.



The Compound Lever.

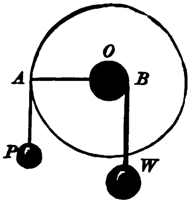
Hay scales are constructed upon the principle of the compound lever. Considering the large mass on the platform as the power, its pressure is transmitted at the points *P* and *P'* (Fig. 52) to a pair of levers of the third class, whose fulcrums are at *F* and *F'*. Pressure is thus produced at *P''* on another lever whose fulcrum is at *F''*. At the remote end of this in turn, pressure is transmitted by the upright bar to the end, *P'''*, of a lever of the first class whose fulcrum is at *F'''*. The weight, *W*, can be adjusted at will until a balance is secured.

FIG. 52.



Hay Scales.

FIG. 53.



Wheel and Axle.

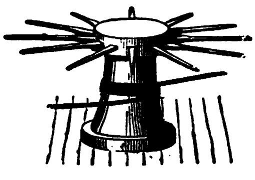
The Wheel and Axle.

The wheel and axle is a kind of perpetual lever. As both arms work continuously, we are not obliged to prop up the *W* and re-adjust the lever. In the windlass used for drawing water from a well, the *P* is applied at the handle, the *W* is the bucket, and the *F* is the axis of the windlass. The long arm of the lever is the length of the handle, and the short arm is the semi-diameter of the axle. This is shown in a cross-section (Fig. 53) where the center, *O*, is the *F*, *OA* the long arm, and *OB* th short arm.—In Fig. 54, instead of turning a handle we take hold *of pins inserted in* the rim of the wheel.—Fig. 55 rep*resents a capstan* used on vessels for raising the anchor. Tr

FIG. 54.

Wheel and Axle.

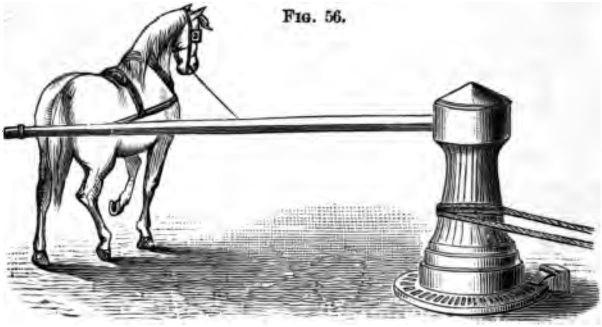
FIG. 55.



Capstan.

P is applied by handspikes inserted in the axle.—Fig. 56 shows a form of the capstan employed in moving buildings, in which a horse furnishes the power.

FIG. 56.



Capstan.

Law of Equilibrium.

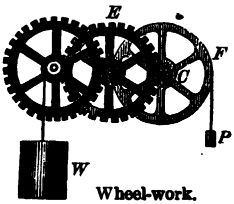
By turning the handle or wheel around once, the rope will be wound around the axle and the W be lifted that distance. Applying the law of mechanics, $P \times$ the circumference of the wheel $= W \times$ circumference of the axle; or, as circles are proportional to their radii,

The power multiplied by the radius of the wheel = the weight multiplied by the radius of the axle.

Wheel-work.

Wheel-work consists of a series of wheels and axles which act upon one another on the principle of the compound lever. The projections on the circumference of the wheel are termed teeth, on the axle, leaves, and the axle itself is called a pinion. If the radius of the wheel F (Fig. 57) be 12 inches, and that of each pinion 2 inches, then a P of 1 lb. will apply a force of 6 lbs. to the second wheel E. If the radius of this be 12 inches, then the second wheel will apply a P of 36 lbs. to the third wheel, which, acting on its axle, will balance a W of 216 lbs. The W will

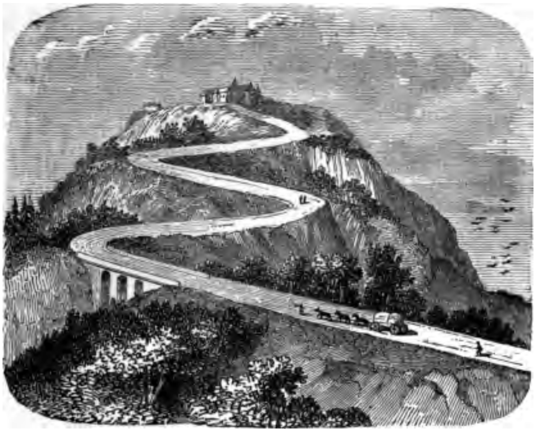
FIG. 57.



Wheel-work.

pass through only $\frac{1}{818}$ the distance of the P. We thus gain power and lose speed. If we wish to reverse this we can apply the P to the axle, and so gain speed. This is the plan adopted in factories, where a water-wheel furnishes abundant power, and spindles or other machines are to be turned with great rapidity.

FIG. 58.



Inclined Plane.

The Inclined Plane.

If we wish to lift a heavy cask into a wagon, we rest one end of a plank on the wagon-box and the other on the ground. We can then easily roll the cask up this inclined plane. When roads are to be made over steep hills, they are sometimes constructed around the hill, like the thread of a screw, or in a winding manner as shown in Fig. 58. There is a remarkable ascent of this kind on Mount Royal, Montreal.

A most excellent example of this element is shown in ship-yards, where vessels are built on an inclined plane and, when finished, allowed to glide downward into the water. It is not easy to conceive in what other way vessels could be launched so readily. (Fig. 59.)

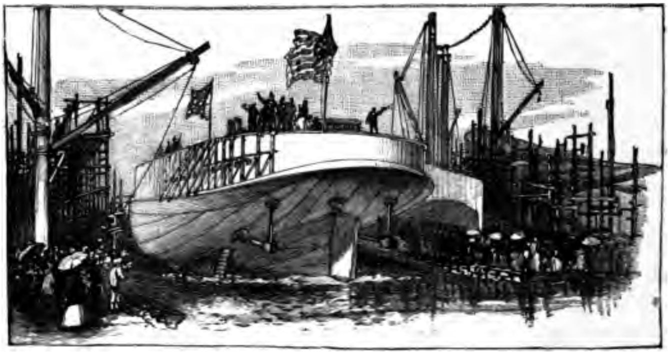
Law of Equilibrium.

In Fig. 60, the P must descend vertically a distance equal to the length of the plane, AC, in order to move

the W from A to C and thus elevate it through the vertical height, BC. Applying the law of mechanics, $P \times$ length of inclined plane $= W \times$ height of inclined plane; hence,

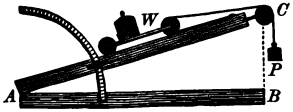
If we roll into a wagon a barrel of pork, weighing 200 lbs., up a plane 12 ft. long and 3 ft. high, we have $200 \times 3 = 600$, $600 \div 12 = 50$. We lift only 50 lbs., or $\frac{1}{4}$ of the barrel, but we move

FIG. 59.



it through four times the space that would be necessary if we could elevate it directly into the wagon. We thus lose speed and gain power. The longer the inclined plane, the heavier the load we can lift, but the more time it will take to do it.

FIG. 60.



Inclined Plane.

If a road ascend 1 ft. in 100 ft., then a horse drawing up a wagon has to lift only $\frac{1}{100}$ of the load, besides overcoming the friction. A body sliding down a perfectly smooth inclined plane acquires the same velocity that it would in falling the same height perpendicularly. A train descending a grade of 1 ft. in 100 ft. tends to go down with a force equal to $\frac{1}{100}$ of its weight.

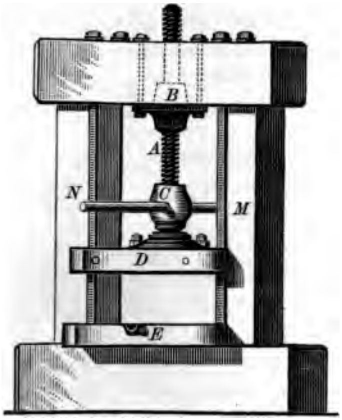
Near Lake Lucerne is a forest of firs on the top of Mount ilatus, an almost inaccessible Alpine summit. By means of a ooden trough, the log is conducted into the water below, a tance of eight miles, in but little more than as many minutes.

The force with which it falls is so prodigious, that if it jumps out of the trough it is dashed to pieces.

The Screw.

The screw (Fig. 61) consists of an inclined plane wound around a cylinder, the former being called the thread, and the latter the body. It works in a nut which is fitted with reverse threads to move on the thread of the screw. The nut may turn on the screw, or the screw in the nut. The P may be applied to either, by means of a wrench or lever. The screw is used in vises; in raising buildings; in copying letters, and in presses for squeezing the juice from apples, sugar-cane, etc.

FIG. 61.

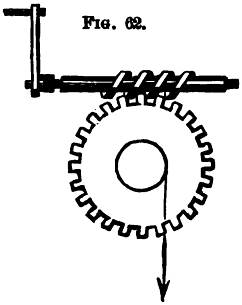


Screw.

The Endless Screw.

The endless screw is a screw secured by shoulders, so that it can not move in the direction of its length, and working into a toothed wheel. When the screw is turned, it imparts motion to the wheel, which, in turn, may be made to move a train of wheel-work.

FIG. 62.



Endless Screw.

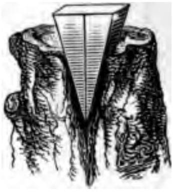
Machines of this kind are used in registering the number of turns of an axle, as, for example, the shaft of a steam-boat. An endless screw (Fig. 62) is arranged so as to turn as many times as the shaft, and is connected with a train of light wheel-work. The wheels bear indices, by means of which the number of turns in any given time may be read off. This arrangement is extensively used in gas and water meters, and also in various branches of manufacture.

When the P is applied at the end of a lever, attached to the head of the screw, it describes a circle of which the lever is the radius. The distance through which the P passes, is the circumference of this circle; and the height to which the W is elevated at each revolution of the screw, is the distance between two of the threads. Applying the law of mechanics, $P \times$ circumference of circle $= W \times$ interval between the threads; hence,

$$P : W :: \text{interval} : \text{circumference}. \quad \ldots\ldots \quad (6)$$

The efficiency of the screw may be increased by lengthening the lever, or by diminishing the distance between the threads.

FIG. 63.



Wedge.

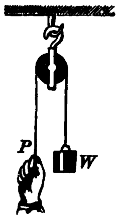
The Wedge. The wedge (Fig. 63) consists generally of two inclined planes placed back to back. It is used for splitting wood and stone and lifting vessels in the dock. Leaning chimneys have been righted by wedges driven in on the lower side. Nails, needles, pins, knives, axes, etc., are made on the principle of the wedge.

The law of equilibrium is the same as that of inclined plane —viz.:

$$P : W :: \text{thickness of wedge} : \text{length of wedge}. \quad \ldots \quad (7)$$

The Law of Equilibrium. In practice, however, this by no means accounts for the prodigious power of the wedge. Friction, in the other mechanical powers, diminishes their efficiency; in this it is essential, else the wedge would fly back and the effect be lost. In the others, the P is applied as a steady pressure; in this it is a sudden blow, and depends upon the kinetic energy expended in the stroke of the hammer.

FIG. 64.



Fixed Pulley.

The Pulley. The pulley consists of a wheel, within the grooved edge of which runs a cord.

A fixed pulley (Fig. 64) merely changes direction of the force. There is no gain of power or speed, as the hand P must move down as much as the

weight *W* rises, and both with the same velocity. It is simply a lever of the first class with equal arms. By its use a man standing on the ground will hoist a flag to the top of a lofty pole, and thus avoid the trouble and danger of climbing up with it. Two fixed pulleys, arranged as shown in Fig. 65, make it possible to elevate a heavy load to the upper story of a building by horse-power.

Fig. 65.

Application of Fixed Pulleys.

Fig. 66.

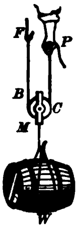
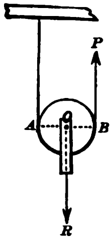


Fig. 67.



Movable Pulleys.

Movable Pulley. A movable pulley is represented in Fig. 66. One half of the barrel is sustained by the hook while the hand lifts the other. As the *P* is one half the *W*, it must move through twice the space; in other words, by taking twice the time, we can lift twice as much. Thus power is gained and time lost.

Fig. 68.

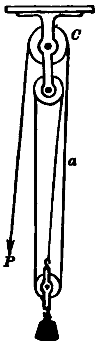


Fig. 69.

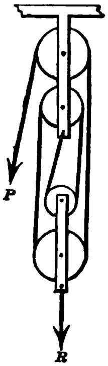


Fig. 70.

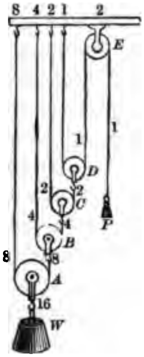
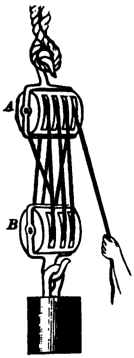


Fig. 71.



Systems of Pulleys.

Tackle Block.

We may also explain the single movable pulley by Fig. 67. *A represents the F, R* the *W* acting in the line OR, and B the

P acting in the line BP. This is a lever of the second class; and as $AO = \frac{1}{3} AB$, $P = \frac{1}{3} W$.

Combinations of Pulleys.

In Fig. 68, we have the W sustained by three cords, each of which is stretched by a tension equal to the P; hence, 1 lb. of power will balance 3 lbs. of weight. In Fig. 69, the P will sustain a W of 4 lbs. In Fig. 70, the cord marked 1 1 has a tension equal to P in each part; the one marked 2 2 has a tension equal to $2P$ in each part, and so on with the others. The total tension acting on W is 16; hence $W = 16\,P$. In this system, D rises twice as fast as C, four times as fast as B, etc. Work must stop when D reaches E, which gives little sweep to A for lifting W. Fig. 71 represents the ordinary "tackle-block" used by mechanics.

Law of Equilibrium.

When a continuous rope is used, let n represent the number of separate parts of the cord which sustain the movable block. We then have

$$P = \frac{W}{n} \quad \ldots\ldots\ldots\ldots \quad (8)$$

When the number of movable and of fixed pulleys is equal, in general $W = P \times$ twice the number of movable pulleys.

Simple machines for moving large bodies are as old as history. The Babylonians knew the use of the lever, the pulley, and the roller. The Romans were acquainted with the lever, the wheel and axle, and the pulley (simple and compound). The Egyptians, it is thought, raised the immense stones used in building the Pyramids, by inclined planes made of earth which was afterward removed. Archimedes, in the third century B.C., discovered the law of equilibrium in the lever. His investigations, however, were too far in advance of his time to be fully understood, and the teachings of Aristotle were long after accepted by scientific men. The law of mechanics, or of Virtual Velocities, as it is called, was discovered by Galileo. It is often said that Archimedes, in allusion to the tremendous power of the lever, asserted that, Give him a fulcrum and he could move the world. Had he been allowed such a chance, "the fulcrum being nine thousand leagues from the center of the earth, with a power of 200 lbs., the geometer would have required a lever

twelve quadrillions of miles long, and the power would have needed to move at the rate of a cannon-ball to lift the earth one inch in twenty-seven trillions of years."

Cumulative Contrivances.

A hammer, club, pile-driver, sling, fly-wheel, etc., are instruments for accumulating energy to be used at the proper moment. Thus we may press a hammer on the head of a nail with all our strength to no purpose; but swing the hammer the length of the arm, and the blow will bury the nail to the head. The strength of our muscles and the attraction of gravity during the fall both gather energy to be exerted at the instant of contact. A fly-wheel by its momentum equalizes an irregular force, or produces a sudden effect. We see the former illustrated in a sewing-machine, and the latter in a punch operated by a treadle. In the one case, the irregular action of the foot is turned into a uniform motion, and in the other it is concentrated in a heavy blow that will pierce a thick piece of metal.

Perpetual Motion.

It is impossible to make a machine capable of perpetual motion. No combination can produce energy; it can only direct that which is applied. In all machinery there is friction; this must ultimately exhaust the power and bring the motion to rest. The only question is, how long a time will be required for the leakage to drain the reservoir. Every year brings to light new seekers after perpetual motion. The mere fact that a man devotes himself to the solution of this impossible problem is now generally regarded as a proof that either his mental balance has been disturbed, or his knowledge of the laws of nature is too meager to entitle him to consideration.

Friction.

Friction is the resistance which one body experiences in moving upon another when the two bodies are pressed together. This resistance arises from inequalities in the surfaces, the projections of the one sinking into the depressions of the other. To overcome the resistance thus produced, a force must be applied sufficient to break off, or bend down, the projecting points, or else to lift the moving body over the inequalities.

Friction is distinguished as sliding and rolling. The former arises when one body is drawn upon another; the latter, when

one body is rolled upon another. Every thing else being equal, the former is greater than the latter.

Friction is greater between surfaces of the same materials than between those of different kinds.

The friction of iron upon iron is greater than that of iron upon copper or brass. For this reason the axles of railway cars being made of steel, the boxes in which they revolve are made of brass or some other metal.

For the same reason, the axles in the wheel-work of the best watches are made to revolve in holes bored in the harder precious stones. Such watches are said to be "jeweled."

Polishing removes projecting points that would catch against each other and increase friction. The application of lubricants like oils, tallow, black-lead, etc., diminishes friction by filling up minute cavities, and smoothing the surfaces.

Advantages of Friction.

Although friction occasions a loss of power in the working of machines, it has some advantages. Common nails and screws would be useless were it not that friction holds them in place. A wedge could not be driven if friction did not hold it and prevent it from rebounding after a blow. A locomotive depends upon friction for its power to draw a heavy train of cars.

Sometimes when great loads are to be moved, the friction of the driving-wheels upon the rails is not sufficient to prevent slipping, and therefore boxes are provided from which sand may be sifted upon the rails when required, thus increasing the friction and enabling the engine to draw its load.

CHAPTER V.

PRESSURE OF LIQUIDS AND GASES.

"THE waves that moan along the shore,
The winds that sigh in blowing,
Are sent to teach a mystic lore
Which men are wise in knowing."

HYDROSTATICS.

HYDROSTATICS treats of liquids at rest. Its principles apply to all liquids; but water, on account of its abundance, is taken as the type.

Pascal's Law.

Liquids are influenced by external pressure only. They transmit pressure equally in all directions, and this acts at right angles upon the surface pressed. This law of liquids is named after the celebrated geometrician, Blaise Pascal, who first enunciated it in 1663. At first thought it may seem impossible for a pressure of 1 lb. to produce a pressure of 100 lbs.; but it should be remembered that the general law of mechanics applies to liquids as well as solids. If a force of 1 lb. on 1 sq. in. should cause motion by pressing through the medium of a liquid on 100 sq. in., the velocity of the body moved will be only $\frac{1}{100}$ of that of the body applying the pressure.

FIG. 72.

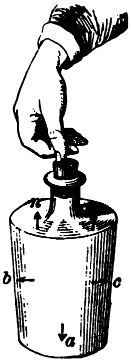


Illustration of Pascal's Law.

As the particles of a liquid move freely among themselves, there is no loss by friction, and any force will be transmitted equally upward, downward, and sidewise. Thus, if a bottle (Fig. 72) be filled with water and a pressure of 1 lb. be applied upon the cork, it will be communicated from particle to particle throughout the water. If the area of the cork be 1 sq. in., the

pressure upon any sq. in. of the glass at *n*, *a*, *b*, or *c*, will be 1 lb. If the inside surface of the bottle be 100 sq. in., a pressure of 1 lb. upon the cork will produce a force of 100 lbs., tending to burst the bottle.

FIG. 73.

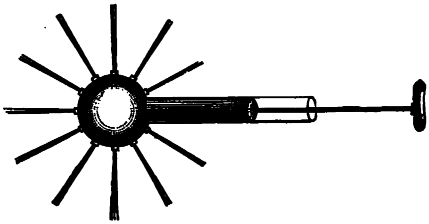
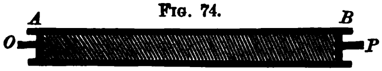


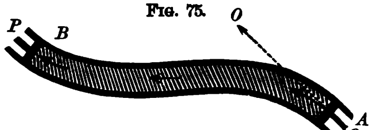
FIG. 74.



Tube with Cylinder of Lead.

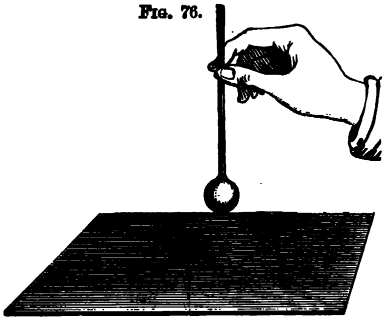
The same principle may be shown by another experiment. A cylinder (Fig. 73) provided with a piston is fitted into a hollow sphere. Perpendicular to the sides of the globe are small tubular openings. Fill the cylinder and globe with water, and press the piston against the water, and it will come from all the orifices equally, and not merely from that which is opposite the piston.

FIG. 75.



Bent Tube Full of Water.

FIG. 76.



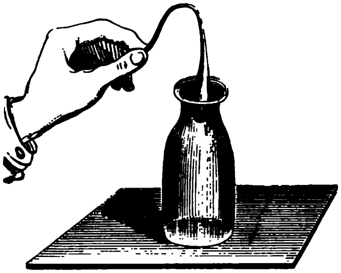
Pounding with a Glass Bulb.

The transmission of pressure by liquids under some circumstances, is more perfect than by solids. Let a straight tube, *AB*, be filled with a cylinder of lead (Fig. 74), and a piston be fitted to the end of the tube. If a force be applied at *P*, it will be transmitted to *O* without sensible loss. If, instead, we use a bent tube (Fig. 75), the force will be transmitted in the lines of the arrows, and will act on *P* but slightly. If, however, we fill the tube with water, the force will be transmitted *without diminution*.

With cords, pulleys, levers, etc., we lose often more than one half of the force by friction; but this "liquid rope" transmits it with no appreciable loss.

Take a glass bulb and stem full of water, as in Fig. 76. The process of filling such bulbs is shown on p. 195. They are cheaply purchased of apparatus dealers, and explain not only this point, but also the method of filling thermometers.

Fig. 77.



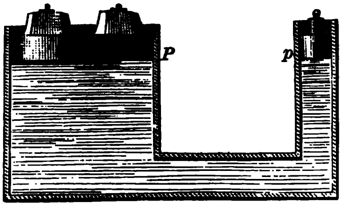
Rupert's Drop in Vial.

If you are careful to let the stem slip loosely through your fingers as the bulb strikes, you may pound it upon a smooth surface. The force of the blow is instantly transmitted from the thin glass to the water, which is almost incompressible, and this makes the bulb nearly as solid as a ball of glass. If a Rupert's drop be held in a closed vial of water so as not to touch the glass (Fig. 77), and the tapering end be broken, the water will transmit the concussion and shatter the vial.

Water as a Mechanical Power.

Take two cylinders, P and p (Fig. 78), fitted with pistons and filled with water. Let the area of p be 1 sq. in. and that of P be 100 sq. in. Then a downward pressure of 1 lb. on each sq. in. of the small piston will produce an upward pressure of 1 lb. on each sq. in. of the large piston. Hence a P of 1 lb. moving at a rate of 1 in. per second will lift a W of 100 lbs. at a rate of $\frac{1}{100}$ of an inch per second.

Fig. 78.



Principle of the Hydrostatic Press.

Pascal announced the discovery of this principle in the following words: "If a vessel full of water closed on all sides has two openings, *the one a hundred times as large as the other, and if each be supplied* with a piston which fits exactly,

a man pushing the small piston will exert a force which will balance that of a hundred men pushing the large one."

The Hydrostatic Press. The hydrostatic press (Fig. 79) utilizes the principle just explained. As the workman depresses the lever O, he forces down the piston a upon the water in the cylinder A. The pressure is transmitted through the bent tube of water d under the piston C, which

Fig. 79.

The Hydrostatic Press.

lifts up the platform K, and compresses the bales. If the area of a be 1 in. and that of C 100 in., a force of 100 lbs. will balance 10,000 lbs. The handle is a lever of the second class. If the distance of the hand from the pivot be ten times that of the piston, a P of 100 lbs. will produce a force of 1,000 lbs. at a. This will become 100,000 lbs. at C. The presses employed for raising the immense tubes of the Britannia Bridge across the

Menai Strait, were each capable of lifting 2,672 tons, and of "throwing water in a vacuum to a height of nearly six miles, or over the top of the highest mountain."

FIG. 80.

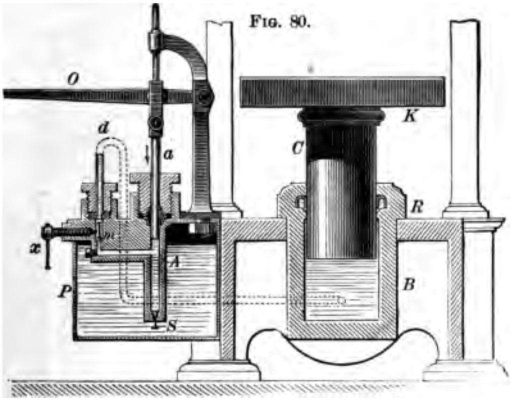
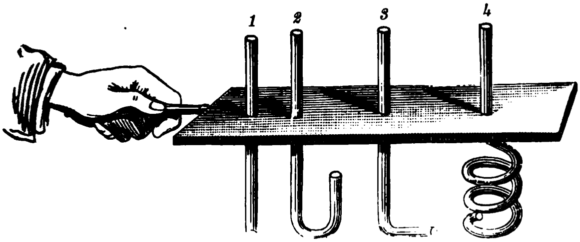


Diagram to Illustrate Hydrostatic Press.

According to the principle of mechanics, $P \times Pd = W \times Wd$, the platform will ascend $\frac{1}{1000}$ of the distance the hand descends. This machine is used for baling hay and cotton, for launching vessels, and for testing the strength of ropes, chains, etc.

FIG. 81.



Transmission of Pressure in all Directions.

Liquids Influenced by Gravity.

The lower part of a vessel of water must bear the weight of the upper part. Thus each particle of water at rest is pressed downward by the weight of the minute column it sustains. It must, in turn, press *in every direction* with the same force, else *it would be driven* out of its place and the liquid would n

longer be at rest. Indeed, when a liquid is disturbed it comes to rest—*i. e.*, there is an equilibrium established—only when this equality of pressure is produced. The following laws obtain:

Four Laws of Equilibrium.

1st. At any point within a liquid at rest, the pressure is the same in all directions. If the series of glass tubes shown in Fig. 81 be placed in a pail of water, the liquid will be forced up 1 by the upward pressure of the water, 2 by the downward pressure, 3 by the lateral pressure, and 4 by the three combined in different portions of the tube. The water will rise in them all to the same height—*i. e.*, to the level of the water in the pail.

FIG. 82.

Increase of Pressure with Depth.

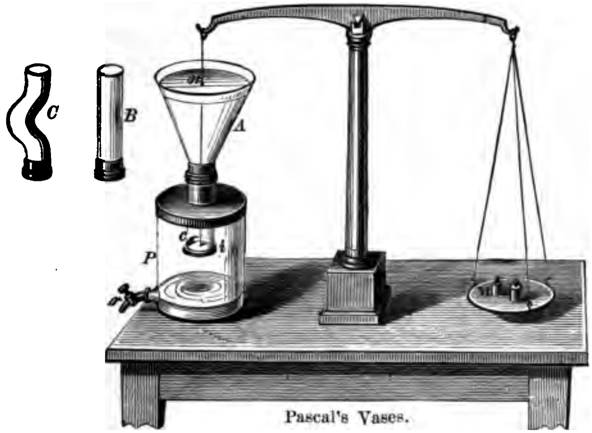
2d. The pressure increases with the depth. Into a tall jar full of water put a bent tube open at both ends, as shown in Fig. 82, a little mercury having been previously poured in so as to fill the bend. The pressure of the water forces down the mercury in the short arm, that in the long arm being exposed only to the pressure of the air. Suppose the difference of level to be an inch when the tube is lowest. Then a column of mercury an inch long will just balance the weight of a column of water of the same thickness and nearly equal in length to the height of the jar. Let the tube now be raised until the surface of the mercury in the short arm is only a fourth of its previous distance from the surface. The difference of level in the two arms is now found to be only a fourth of an inch.

A cubic foot of water weighs about 62.5 lbs. (1,000 oz.); the same volume of sea-water weighs 64.4 lbs.; hence the pressure is proportionally greater in sea-water. At the greatest

depth ever measured in the sea, a little over five miles, the pressure is about six tons on every square inch. An empty glass bottle securely stoppered may be crushed before sinking a hundred yards.

3d. The pressure does not depend on the shape or size of the vessel, but on the area and depth. In the apparatus shown in Fig. 83, a disk is held up by a string against the bottom of an open tube, to which may be screwed vessels of different shapes and sizes, such as *A*, *B*, or *C*. The string is attached to the beam of a balance. In the scale-pan is put such a weight,

FIG. 83.



Pascal's Vases.

M, as to balance the pressure of the liquid against the disk when the vessel is full up to a certain point, *n*. The addition of any more liquid causes the disk to sink and thus spill the liquid, whether the large vessel, *A*, or the smaller ones, *B* or *C*, be used. Against the same area at the bottom the same pressure is obtained even if *A* is three times *B* in volume, provided the depth be kept the same. If the depth of water be increased, *M* has to be increased in the same ratio. Thus a pound of water in *B* may be made to exert a greater pressure at the bottom than 2 lbs. of water in *A*.

The Hydrostatic Bellows is an application of the principle *just discussed, and is like* the Hydrostatic Press on a sma

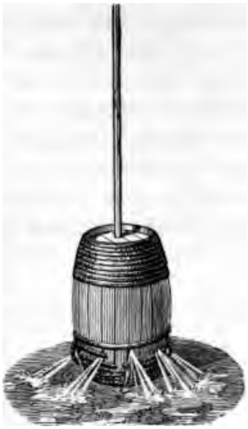
scale. It consists of two boards connected by a band of leather and provided with a supply tube for water. Suppose the area of *C* (Fig. 84) to be 500 sq. in., and the area across the small tube *A* to be a single sq. in. Let the stiffness of the leather, along with an added weight on *C*, be equivalent to 100 lbs. Then only one fifth of a pound of water in *A* is needed to balance the 100 lbs. If at *A* we use a larger tube across which the area is 10 sq. in., then 2 lbs. of water in it are required to maintain equilibrium. The surface of the water in *A* will be about 6 in. above *C*, whether the large or small tube is used. If a cubic inch more be poured into the small tube, the same quantity will be forced into the bellows, so that *C* rises $\frac{1}{500}$ of an inch. If a larger weight is put on *C*, a higher column in *A* is required, but still *C* can be raised by any addition to *A*, however small.

FIG. 84.

Hydrostatic Bellows.

A strong cask fitted with a small pipe 30 or 40 feet long (Fig. 85), if filled with water will be burst asunder. Suppose the pipe to have an area of $\frac{1}{40}$ sq. in., and to hold $\frac{1}{2}$ lb. of water. The pressure on each $\frac{1}{40}$ of an inch of the interior of the cask would be $\frac{1}{2}$ lb., or 880 lbs. on each sq. ft. —a pressure no common barrel could sustain. The principle that a small quantity of water will thus balance another quantity, however large, or will lift any weight, however great, is frequently termed the "Hydrostatic Paradox." It is only an instance of a general law, and is no more paradoxical than the action of the lever. The pressure is as great as if the tube were of the same diameter as the cask. In a coffee-*ot, the small quantity* of liquid in the spout balances the large

FIG. 85.



Bursting a Cask.

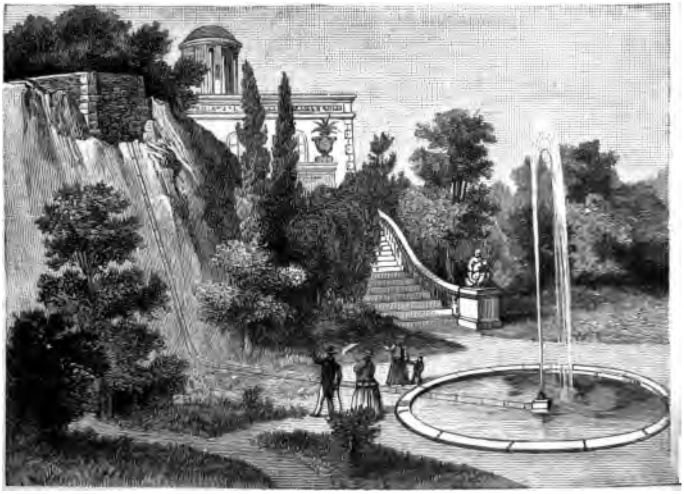
FIG. 86.

Water in Communicating Vessels.

quantity in the vessel. If it were not so, it would rise in the spout and run out.

Water seeks its level. In the apparatus shown in Fig. 86,

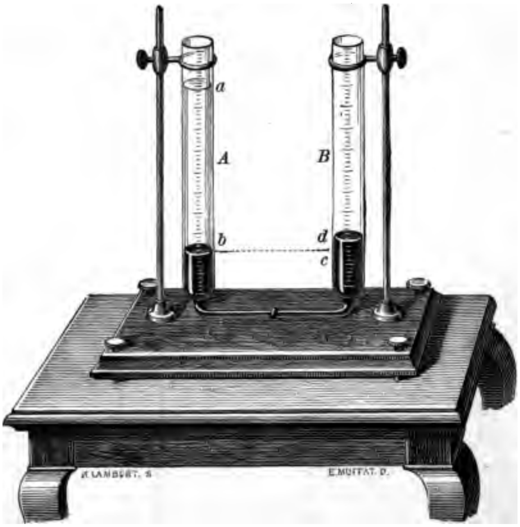
FIG. 87.



Construction of a Fountain.

the water rises to the same height in the various tubes which communicate with one another, because so long as the surfaces are not at the same level a particle below any surface must be unequally pressed from opposite sides, and must move until equilibrium is attained. In Fig. 87, a tank is situated on a hill, whence the water is conducted underground through a pipe to the fountain. In theory, the jet will rise to the level of the reservoir, but in practice it falls short, owing chiefly to the friction in the pipe, the weight of the falling drops, and the resistance of the air.

FIG. 88.



Vessels containing Liquids of different Densities.

When liquids of different densities are contained in communicating vessels, they will be in equilibrium when the heights of the columns are inversely as their densities.

This principle is demonstrated by means of an apparatus shown in Fig. 88. The apparatus consists of two glass tubes, *A* and *B*, open at top, and communicating at bottom by a smaller tube. If a quantity of mercury be poured

into one of the tubes, it will come to a level in both tubes, according to the principle explained in the preceding article. If a quantity of water be poured into the tube *A*, the level of the mercury in that tube will be depressed, whilst it will be elevated in the tube *B*. The difference of level, *d c*, can be determined by the graduated scales on the tubes. It will be found by measurement, that the column of water, *a b*, is 13.6 times as high as the column of mercury, *d c*, which it supports. It will be shown hereafter, that mercury is 13.6 times as dense as water; hence the principle is proved. Other liquids may be employed with similar results.

Equilibrium of Heterogeneous Liquids.

If liquids of different densities, but which do not mix, be poured into a vessel, they will arrange themselves in the order of their densities, the heaviest being at the bottom, and the upper surface of each will be horizontal.

FIG. 89.

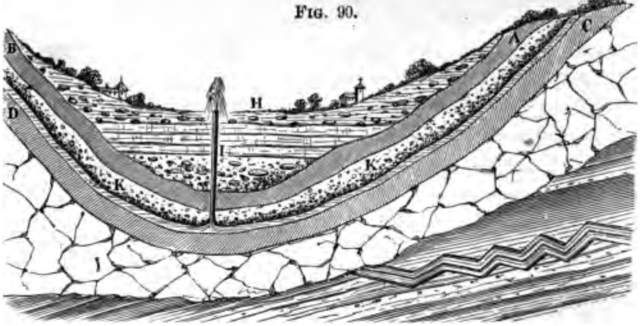
This is shown by a vial (Fig. 89) containing liquids of different densities, as mercury, water saturated with potassium carbonate, alcohol reddened by aniline, and naphtha. We can float on the different surfaces balls of cork, wax, wood, and glass. If the vial be shaken, the liquids appear to mix; but if allowed to stand, they arrange themselves in horizontal layers, the densest liquid at the bottom.

It is in accordance with this principle that cream rises on milk, and oil on water. The principle is often employed to separate liquids of different density by the process of decanting.

Artesian Wells.

Let *A B* and *C D* represent curved strata of clay impervious to water, and *K K* a layer of gravel. The rain falling on the hills filters down to *C D*, and collects in this basin. If a well be bored at *H*, as soon as it reaches the gravel the water will rush upward under the tremendous lateral pressure, to the surface of the

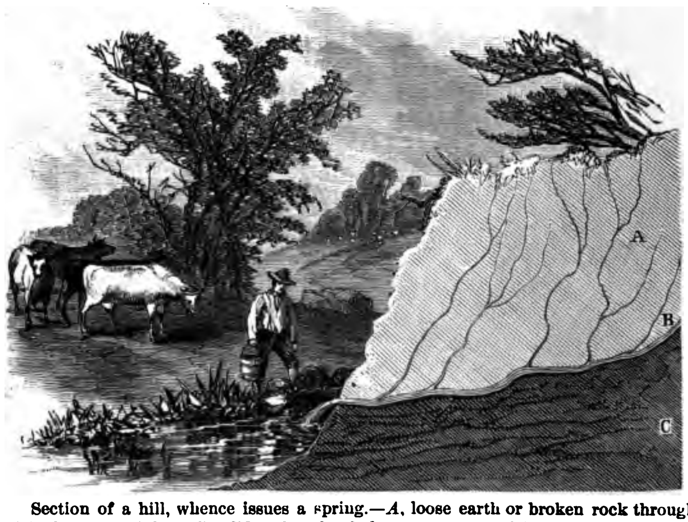
FIG. 90.



Artesian Well.

ground, often spouting high in air. Such wells are called Artesian Wells, and are so named because they have long been used

FIG. 91.

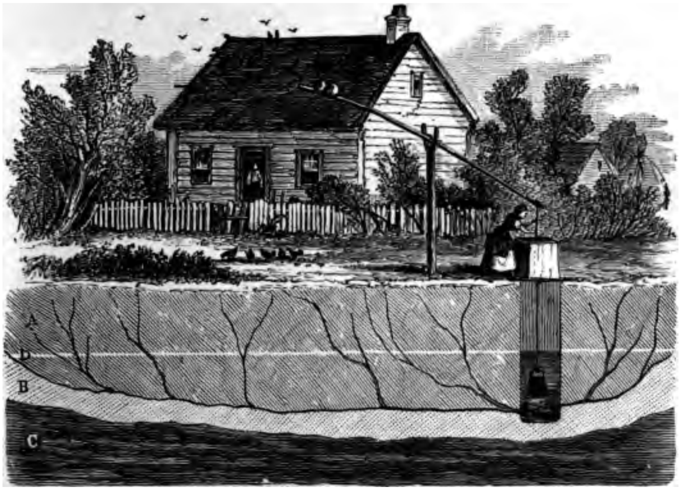


Section of a hill, whence issues a spring.—*A*, loose earth or broken rock through which the water sinks ; *C*, solid rock or hard clay not penetrated by water ; *B*, seam or channel in which the water flows.

in the province of Artois (Latin, Artesium), France. They were, however, early employed by the Chinese for the purpose of *procuring gas and salt water.*

The famous well at Grenelle, Paris, is at the bottom of a basin which extends miles from the city. It is about 1,800 feet deep, and furnishes 656 gallons of water per minute. The two wells of Chicago are about 700 feet deep, and discharge daily about 432,000 gallons. Being situated on the level prairie, the force with which the water comes to the surface indicates that

FIG. 92.



Section of the ground or rock, showing how wells are supplied. *A*, The part through which the rain water percolates; *C*, Rock or clay impervious to water; *B*, Seam or stratum in which the water passes; *D*, Level of water in porous ground.

it may be supplied perhaps from Rock River, 100 miles distant. There are also valuable artesian wells at Louisville, Kentucky, and at Charleston, South Carolina. When the water comes from a great depth it is generally warm.

Of the rain which falls on the land, a part runs directly to the streams and part soaks into the soil. The latter portion may filter down to an impermeable layer of rock or clay, and then run along till it oozes out at some lower point as a spring; or, if it can not escape, it will collect in the ground. If a well be sunk into this subterranean reservoir, the water will rise in it *to the level of the source.*

"From a forgetfulness of this principle the company which dug the Thames and Medway Canal, England, incurred heavy damages. Having planned the canal to be filled at high tide, the salt water spread immediately into all the wells of the surrounding region. Had the canal been dug a few feet lower, the evil would have been avoided."—ARNOTT.

To find the pressure on the bottom of a vessel, multiply the area of the base in square feet by the vertical height in feet, and that product by the weight of a cubic foot of the liquid.

FIG. 93.

The Curvature of a Water Level.

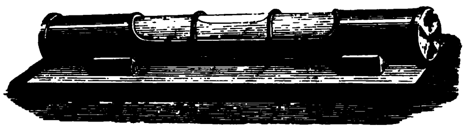
To find the pressure on the side of a vessel, multiply the area of the side in square feet by half of the vertical height in feet, and that product by the weight of a cubic foot of the liquid. This clause of the rule holds only when the center of gravity of the side is at half the vertical height. In general, the depth of its center of gravity below the surface should be used as the multiplier. The pressure on the bottom of a cubical vessel of water is the weight of the water; on each side, one half; and on the four sides, twice the weight; therefore, on the five sides the pressure is three times the weight of the water.

The surface of standing water is said to be level—*i. e.*, horizontal to a plumb-line. This is true for small sheets of water, but for larger bodies an allowance must be made for the spherical form of the earth (Fig. 93). The curvature is 8 inches for the first mile, and increases as the square of the distance.

For two miles it is 8 inches $\times 2^2 = 32$ inches. If one's eye were at the level of still water, he could barely see the top of an object 67 feet high at a distance of 10 miles in a perfectly clear atmosphere.

The spirit-level is an instrument used by builders for leveling. It consists of a slightly-curved glass tube nearly full of alcohol, so that it holds only a bubble of air. When the level is horizontal, the bubble remains at the center of the upper side of the tube.

FIG. 94.



The Spirit-level.

Specific gravity, or relative weight, is the ratio of the weight of a substance to that of the same volume of another substance taken as a standard. Water is taken as the standard for solids and liquids, and air for gases. "The water must be at 39.2° F., its greatest density. In all exact measurements, especially of standards, it is necessary to know the temperature. For the scale that is a foot long to-day may be more or less than a foot long to-morrow; the measure that holds a pint to-day may hold more or less than a pint to-morrow. Nay, more, these measures may not be the same in two consecutive moments. When a carpenter takes up his rule and applies it to some object, the size of which he wishes to determine, it becomes in that instant longer than it was before; when a druggist grasps his measuring glass in his hand to dispense some of his preparations, the glass increases in size. A person enters a cool room, and at once it becomes more capacious, for its walls, ceiling, and floor, because of the heat he imparts, immediately expand."—DRAPER.

A cubic inch of sulphur weighs twice as much as a cubic *inch of water; hence its* specific gravity$=2$. A cubic inch of

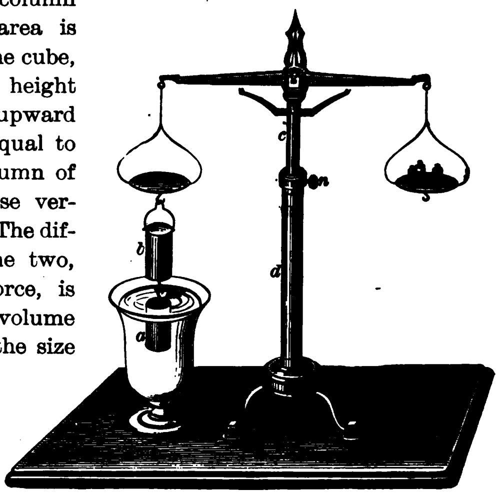
carbonic-acid gas weighs 1.52 times as much as the same volume of air; hence its specific gravity=1.52. The term density is often used in the same sense as specific gravity, especially in relation to gases.

Fig. 95.

Immersed Cube.

The cube *a b c d* is immersed in water (Fig. 95). The lateral pressure at *a* is equal to that at *b*, because both sides are at the same depth; hence the body has no tendency toward either side of the jar. The upward pressure at *c* is greater than the downward pressure at *d*, because its depth is greater; hence the cube has a tendency to rise. This upward pressure is called the buoyant force of the water. It is equal to the weight of the liquid displaced. For the downward pressure at *d* is the weight of a column of water whose area is that of the top of the cube, and whose vertical height is *n d*, and the upward pressure at *c* is equal to the weight of a column of the same size whose vertical height is *n c*. The difference between the two, or the buoyant force, is the weight of a volume of water equal to the size of the cube.

Fig. 96.

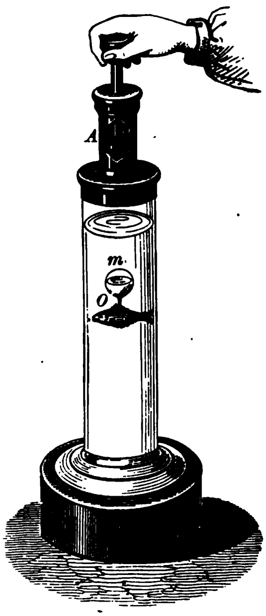


Cylinder-and-bucket Experiment.

The same principle is shown in the "cylinder-and-bucket experiment." The cylinder *a* exactly fits in the bucket *b* (Fig. 96). When the glass vessel in which the cylinder hangs is empty, the apparatus is

balanced by weights placed in the scale-pan. Next, water is poured into the glass vessel. Its buoyant force raises the cylinder and depresses the opposite scale-pan. Then water is dropped into the bucket; when it is exactly full, the scales will balance again. This proves that "a body in water is buoyed up by a force equal to the weight of the water it displaces." This is called Archimedes' law.

FIG. 97.



The principle is so called because it was first discovered by the illustrious philosopher of that name. He was led to the discovery in an attempt to detect a fraud perpetrated upon Hiero of Syracuse by a goldsmith who had been employed to make a golden crown. The artisan mixed a portion of silver with the gold that was given him for making the crown, but, by means of the principle above explained, Archimedes was able to determine the exact amount of each material employed.

Illustration of the Principles of Flotation.

The principles of flotation may be illustrated by an instrument shown in Fig. 97, which, under various forms, may be procured in the shops as a child's toy.

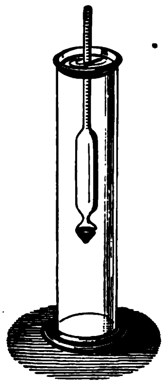
In the form shown, it consists of a high and narrow glass vessel, surmounted by a brass cylinder, *A*, in which is an air-tight piston that may be raised or depressed by the hand. The vessel is partially filled with water, and contains a light body, as a fish, hollow, and of porcelain or glass. The fish is attached to a sphere of glass, *m*, filled with air, and with a small hole, *o*, at its lower side, through which water can flow in or out, as the pressure is increased or diminished.

Under ordinary circumstances the sphere, *m*, with its attached fish, *floats at the surface* of the water. If the piston is *depressed, the air beneath it* is compressed, and acting upon the

water forces a portion of it into the globe. The apparatus then becomes more dense than the water, and sinks. By relieving the pressure, the air in the globe expands and drives the water out, when it again floats on the surface. The experiment may be repeated at pleasure.

To find the specific gravity of a heavy solid, weigh the body in air, and in water; the difference is the weight of its volume of water; divide its weight in air by its loss of weight in water; the quotient is the specific gravity. Thus, sulphur loses one half its weight when immersed in water; hence it is twice as heavy as water, and its specific gravity = 2. In careful measurements an allowance is made for the weight of the air displaced by the body, so that its weight in a vacuum becomes known. Strictly, it is the weight in a vacuum that has to be compared with the loss of weight in water. If the body will not sink in water, attach it to a heavy body. 1. Weigh the lighter body in air (A). 2. Weigh the heavy body in water (B). 3. Weigh both together in water (C). Now C is less than B because the light body buoys up the heavy one; *i. e.*, its weight A is more than balanced, and is replaced by an upward or lifting force $= B - C$. Therefore the loss of the light body in water $= A \times \overline{B - C}$ $\therefore$ spec. grav. $= \dfrac{A}{A \times \overline{B - C}}$.

FIG. 98.



Hydrometer.

The specific-gravity flask is a bottle which holds exactly 1,000 grains of water. If it will hold 1,840 grains of sulphuric acid, the specific gravity of the acid is 1.84.

The hydrometer consists of a glass tube, closed at one end, and having at the other a bulb containing mercury. A graduated scale is marked upon the tube. The alcoholometer, used in testing alcohol, is so balanced as to sink in pure water to the zero point. As alcohol is lighter than water, the instrument will descend for every addition of spirits. The degrees of the scale indicate the percentage of alcohol. Similar instruments are used for determining the strength of milk, acids, etc.

Multiply the weight of one cubic foot of

water by the specific gravity of the substance, and that product by the number of cubic feet, and you will find the weight of a given volume of any substance. What is the weight of three cubic feet of cork? *Solution:* 1,000 oz. × .240 = 240 oz.; 240 oz. × 3 = 720 oz.

TABLE OF SPECIFIC GRAVITY.

Iridium	21.80	Zinc	7.15	Pine Wood	.66
Platinum	21.53	Diamond.... about	3.50	Cork	.24
Gold	19.34	Flint Glass	2.76	Sulphuric Acid	1.84
Mercury	13.59	Chalk	2.65	Water from Dead Sea	1.24
Lead	11.36	Sulphur	2.00	Milk	1.03
Silver	10.50	Ice	.93	Sea-water	1.03
Copper	8.90	Potassium	.86	Absolute Alcohol	.79
Cast-iron	7.21	Quicklime	.80		

To find the volume of a given weight of any substance, multiply the weight of a cubic foot of water by the specific gravity of the substance, and divide the given weight by that product. The quotient is the required volume in cubic feet. What is the volume of 20,000 oz. of lead? *Solution:* 1,000 oz. × 11.36 = 11,360; 20,000 ÷ 11,360 = 1.76 + cu. ft.

To find the volume of a body, weigh it in water. The loss of weight is the weight of the displaced water. Then, as a cubic foot of water weighs 1,000 oz., we can easily find the volume of water displaced. A body loses 10 oz. on being weighed in water. The displaced water weighs 10 oz. and is $\frac{1}{100}$ of a cubic foot; this is the exact volume of the body.

Nicholson's Hydrometer.

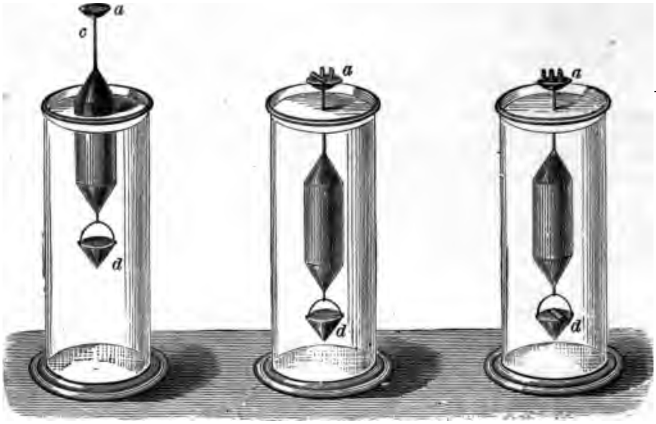
Nicholson's Hydrometer consists of a hollow cylinder of metal, as shown in Fig. 99, weighted at the bottom by a heavy body, *d*, to make it float erect, and terminating above by a thin stem, *c*, which supports a scale-pan, *a*. The instrument is so constructed that when a given weight, say 500 grains, is placed in the pan, it will sink in distilled water to a notch, *c*, on the stem.

The method of determining the specific gravity by means of this instrument is shown in Figs. 100 and 101. Suppose it were required to determine the specific gravity of a small bar of iron weighing less than 500 grains.

The bar is placed in the pan and weights added till it sinks *to the notch in the stem,* as shown in Fig. 100. These weights

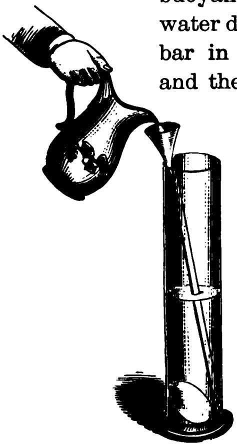
subtracted from 500 grains, give the weight of the bar in air. Next place the bar in the cup, *d*, as shown in Fig. 101, and

Fig. 99. Fig. 100. Fig. 101.



add weights enough to make the instrument sink again to the notch in the stem. The last weights will denote the buoyant effort of the fluid, or the weight of the water displaced by the bar. Divide the weight of the bar in air by the weight of the displaced water, and the result will be the specific gravity sought.

Fig. 102.



Egg in Water.

A body will float in water when its weight is not greater than that of an equal volume of the liquid, and its weight always equals that of the fluid displaced. An egg dropped into a glass jar half full of water (Fig. 102) sinks directly to the bottom. If, by means of a funnel with a long tube, we pour brine beneath the water, the egg will rise. We may vary the experiment by not dropping in the egg until we have half filled the jar with the brine. The egg will then fall to the center and there float. Almost *any solid, if dissolved* in water, fills the pores of the water

without adding much to its volume. This increases its density and buoyant power. A person can therefore swim more easily in salt than in fresh water.

Bayard Taylor says that he could float on the surface of the Dead Sea, with a log of wood for a pillow, as comfortably as if lying on a spring mattress. Another traveler remarks, that on plunging in he was thrown out again like a cork; and that on emerging and drying himself, the crystals of salt which covered his body made him resemble an "animated stick of rock-candy."

An iron ship will not only float itself, but also carry a heavy cargo, because it displaces a great volume of water.—A body floating in water has its center of gravity at the lowest point, when it is in stable equilibrium. Herschel tells an amusing story of a man who attempted to walk on water by means of large cork boots. Scarcely, however, had he ventured out ere the law of gravitation seized him, and all that could be seen was a pair of heels, whose movements manifested a great state of uneasiness in the human appendage below.

Fishes have air-bladders, by which they can rise or sink at pleasure. By compressing the air-bladder, the fish diminishes the volume of its own body. The buoyant effect of the water is correspondingly decreased and the fish descends. By relaxing the compression on the bladder, the air in it expands and the fish rises. It was formerly thought that a fish in water has no weight. It is said that Charles II. of England once asked the philosophers of his time to explain this phenomenon. They offered many wise conjectures, but no one thought of trying the experiment. At last a simple-minded man balanced a vessel of water, and on adding a fish, found it weighed just as much as if placed on a dry scale-pan.

Hydrostatics.

Hydrostatics is comparatively a modern science. The Romans had a knowledge of the fact that "liquids rise to the level of their source," but they had no means of making iron pipes strong enough to resist the pressure. The ancient engineers sometimes availed themselves of this principle. Not far from Rachel's Tomb, Jerusalem, are the remains of a conduit once used for supplying the city with water. The valley was crossed by means of an

inverted siphon. The pipe was about two miles long and fifteen inches in diameter. It consisted of perforated blocks of stone, ground smooth at the joints, and fastened with a hard cement.

They were therefore forced to carry water into the Imperial City by means of enormous aqueducts, one of which was 63 miles long, and was supported by arches 100 feet high. The ancient Egyptians and Chaldeans were probably the first to investigate the most obvious laws of liquids from the necessity of irrigating their land. Archimedes, in the third century B.C., invented a kind of pump called Archimedes' Screw, demonstrated the principle of equilibrium, known now as "Archimedes' Law," and found out the method of obtaining the specific gravity of bodies. The discovery of the last is historical. Hiero of Syracuse suspected that a gold crown had been fraudulently alloyed with silver. He accordingly asked Archimedes to find out the fact without injuring the workmanship of the crown. One day going into a bath-tub full of water, the thought struck the philosopher that as much water must run over the side as was equal to the volume of his body. Electrified by the idea, he sprang out and ran through the streets, shouting: "Eureka!" (I have found it!)

The ancients never dreamed of associating the air with gross matter. To them it was the spirit, the life, the breath. Noticing how the atmosphere rushes in to fill any vacant space, the followers of Aristotle explained it by saying, "Nature abhors a vacuum." This principle answered the purpose of philosophers for 2,000 years. In 1640, some workmen were employed by the Duke of Tuscany to dig a deep well near Florence. They found to their surprise that the water would not rise in the pump as high as the lower valve. More disgusted with nature than nature was with the vacuum in their pump, they applied to Galileo. The aged philosopher answered —half in jest, we hope, certainly he was half in earnest—"Nature does not abhor a vacuum beyond 34 feet." His pupil, Torricelli, however, discovered the secret. He reasoned that there is a force which holds up the water, and as mercury is $13\frac{1}{2}$ times as heavy as water, it would sustain a column of that liquid only 34 feet $\div 13\frac{1}{2} = 30$ inches high. Trying the experiment shown in Fig. 101, he verified the conclusion that the

weight of the air is the unknown force. But the opinion was not generally received. Pascal next reasoned that if the weight of the air is really the force, then at the summit of a high mountain it is weakened, and the column would be lower. He accordingly carried his apparatus to the top of a tower, and finding a slight fall in the mercury, he asked his brother-in-law, Perrier, who lived near Puy de Dôme, a mountain in Southern France, to test the conclusion. On trial, it was found that the mercury fell three inches. "A result," wrote Perrier, "which ravished us with admiration and astonishment." Thus was discovered the germ of our modern barometer, and the dogma of the philosophers soon gave place to the law of gravitation and our present views concerning the atmosphere.

HYDRODYNAMICS.

Hydrodynamics treats of liquids in motion. In this, as in Hydrostatics, water is taken as the type. In theory, its principles are those of falling bodies, but in practice they can not be relied upon except when verified by experiment. The discrepancy arises from changes of temperature, which vary the fluidity of the liquid, from friction, the shape of the orifice, etc.

Flow of Liquids from Orifices.

It has already been shown that the pressure exerted by a fluid is proportional to its depth. If, then, in a vessel filled with water, openings be made at different depths from the surface, as shown in Fig. 103, it is evident that the water will flow out with the greatest velocity at the greatest depth from the surface.

But the velocity does not increase in the simple ratio of the depth; it is found to be in proportion to the square root of the depth. This result is in accordance with the laws of falling bodies.

The water issues from the jet at v with a velocity which would carry it to the same height with the surface in h, were it not for friction and the resistance of the air.

This velocity is the same that would be acquired by a body in falling *freely through* the distance from h to v.

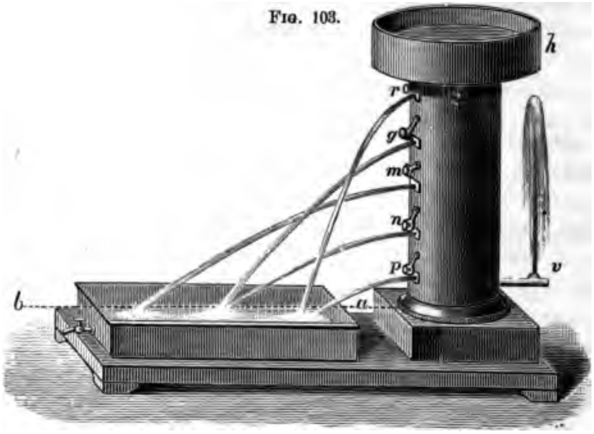
Since the whole space described by a falling body is propor-

tioned to the square of the time, while the velocity increases in the simple ratio of the time, it follows that the velocity acquired is proportioned to the square root of the whole space through which the body falls.

Thus, if an aperture be made in a vessel containing water, $16\frac{1}{12}$ feet below the surface, the water will escape with a velocity of $32\frac{1}{6}$ feet per second; for this is the velocity acquired by a body falling through that distance.

A stream thrown out in any other direction than the vertical will have the same velocity, since the pressure to which the velocity is due remains the same.

FIG. 103.



Jets from Different Orifices.

The range of a horizontal jet will be greatest when it is half-way between the surface and the level of the place where it strikes. Thus the jet shown at m in the figure has the greatest range. Jets issuing from orifices at equal distances above and below the middle point, as at g and n, will have the same range.

Rules Concerning a Jet.

The velocity of a jet is the same as that of a body falling from the surface of the water. We can see that this must be so, if we recall two principles: 1st. "A jet will rise to the level of its source;" 2d. "To elevate a body to any height, it must have

the same velocity that it would acquire in falling that distance." It follows that the velocity of a jet depends on the height of the liquid above the orifice.

To find the velocity of a jet of water, use the formula that the square of the velocity equals twice the force of gravity multiplied by the distance of the orifice below the surface of the water. If the depth of water above the orifice is 49 feet, then the velocity equals the square root of $2 \times 32 \times 49$, *i. e.*, 56 feet.

To find the quantity of water discharged in a given time, multiply the area of the orifice by the velocity of the water, and that product by the number of seconds. What quantity of water will be discharged in five seconds from an orifice having an area of ½ sq. foot at an average depth of 49 feet? At that depth, the velocity equals (as shown above) 56 feet per second; multiplying by ½, we have 28 cubic feet discharged in one second and 140 cubic feet in five seconds. In practice, much less than this can be realized. If, at a foot below the surface, an opening will furnish one gallon per minute, to double that quantity the opening must be four feet below the top. Again, if a certain power will force through a nozzle of a fire-engine a given quantity of water in a minute, to double the quantity the power must be quadrupled.

Effect of Tubes.

If we examine a jet of water, we see its size is decreased just outside the orifice to about two thirds that at the opening. This neck is called the vena contracta, and is caused by the water producing cross currents as it flows from different directions toward the orifice. If a tube of a length twice or thrice the diameter of the opening be inserted, the water will adhere to the sides so that there will be no contraction, and the flow be increased to about 80 per cent. of the theoretical amount. If the tube be conical, and inserted with the large end inward, the discharge may be augmented to 95 per cent.; and if the outer end be flaring, it may reach 98 per cent. Long tubes or short angles, by friction, diminish the flow of water.

A fall of three inches per mile is sufficient to give motion to water, and produce a velocity of as many miles per hour. The Ganges descends but 800 feet in 1,800 miles. Its waters

require a month to move down this long inclined plane. "The fall of 800 feet would theoretically give a velocity of more than 150 miles per hour. This is reduced by friction to about three miles." A fall of three feet per mile will make a mountain torrent. The current moves more swiftly at the center than near the shores or bottom of a channel since there is less friction.

Flow of Water in Rivers.

FIG. 104.

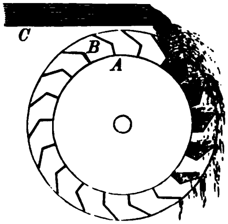
Cut Showing Application of Overshot Wheel.

Water-wheels.

Water-wheels are machines for using the force of falling water. By bands of cog-wheels the motion of the wheel is conducted from the axle into the mill. The principle is that of a lever with the *P acting on the short* arm. In this way the movement of the

slow creaking axle reappears in the swiftly buzzing saw or flying spindle.

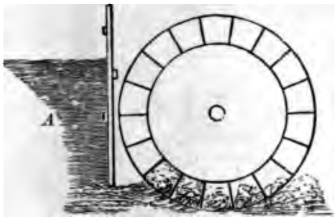
FIG. 105.



The Overshot Wheel.

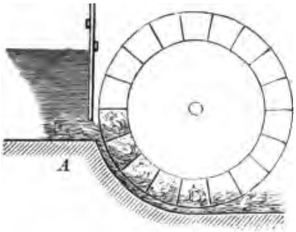
The Overshot Wheel has on its circumference a series of buckets which receive the water flowing from a sluice, *C*. These hold the water as they descend on one side, and empty it as they come up on the other. Overshot wheels are valuable where a great fall can be secured, since they require but little water. If W denotes the weight of the water and h the distance it falls, then the total work $= Wh$. Of this amount, 75 per cent. can be made available under good conditions.

FIG. 106.



Undershot Wheel.

FIG. 107.



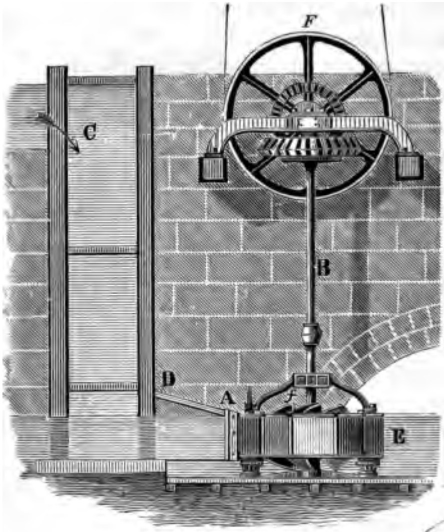
Breast-wheel.

The Undershot Wheel has projecting boards, or floats, which receive the force of the current. It is of use where there is little fall and a large quantity of water. It utilizes not more than 25 per cent. of the energy of the water.

The Breast-wheel (Fig. 107) is a medium between the two kinds already named.

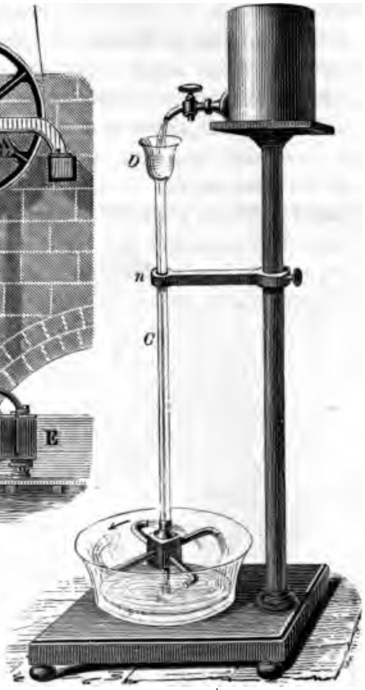
The Turbine Wheel is placed horizontally and immersed in the water. In Fig. 108, *C* is the dam and *DA* the spout by which the water is furnished. *E* is a scroll-like casing encircling the wheel, and open at the center above and below. The axis of the wheel is the vertical cylinder *B*, from which radiate plane-floats against which the water strikes. This form utilizes as high as 90 per cent. of the energy. *F* is a band-wheel which conducts the power to the machinery.

Fig. 108.



Turbine Wheel.

Fig. 109.



Barker's Mill.

The principle of the unbalanced pressure of a column of water may also be employed. It is illustrated in Barker's Mill, or Reaction-wheel. This consists of an upright cylinder with horizontal arms, on the opposite sides of which are small apertures. It rests in a socket, so as to revolve freely. Water is supplied from a tank above. If the openings in the arms are closed when the cylinder is filled with water, the pressure is equal in all directions and the machine is at rest. If now we open an aperture, the pressure is relieved on that side, and the arm flies back on account of the unbalanced pressure of the column of water above. Revolving fire-works and the whirligig, used for watering lawns and as an ornament in fountains, are constructed on the same principle. A little ingenuity will enable one to easily construct a Reaction-wheel of straws or quills, pouring the water into the upright tube by

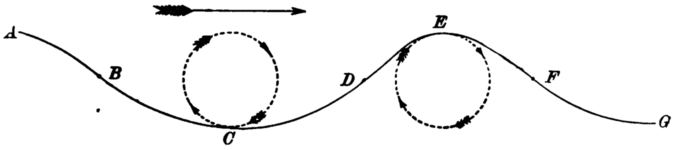
means of a pitcher, or admitting it slowly through a siphon from a pail of water placed on a table above.

Waves.

Waves are produced by the friction of the wind against the surface of the water. The wind raises the particles of water and gravity draws them back again. They thus vibrate up and down, but in deep water the liquid mass does not advance. The forward movement of the wave is an illusion. The form of the wave progresses like the apparent motion of the thread of the screw which we turn in our hand, or the undulations of a rope or carpet which is shaken, or the stalks of grain which bend in billows as the wind sweeps over them.

The corresponding parts of different waves are said to be like phases. Thus, in Fig. 110, *A* and *E*, *B* and *F*, *C* and *G*

FIG. 110.



are like phases. The distance between two like phases, or between the crests of two succeeding waves, is called a wave-length. Thus the distance *AE*, or *BF*, or *CG* is a wave-length. Opposite phases are those parts which are vibrating in opposite directions, as *E* and *C*, or *B* and *D*. The successive particles of water move each in an ellipse, and in regular succession, so that when a particle at *E* is moving forward, one at *C* is moving backward, one at *B* upward, and one at *D* downward. This is easily observed at sea. Near the shore, the oscillations become shorter; the lower particles being checked in their elliptic motion by the friction on the sandy beach, the front becomes well-nigh vertical, and the upper part curls over and falls beyond. The size of "mountain billows" has been exaggerated. Along the coast in a gorge, they may reach 90 feet, but in the open sea the highest wave, from the deepest "trough" to the very topmost "crest," rarely measures over 30 feet.

A tide-wave may be setting steadily toward the west; waves from distant storms may be moving upon this; and, above the whole, ripples from the breeze then blowing may diversify the surface. These different systems will be distinct, yet the joint effect may be very peculiar. If any two systems coincide with like phases,—the crest of one meeting the crest of

FIG. 111.

Interference of Waves.

the other, and the furrow of one meeting the furrow of the other,—the resulting wave will have a height equal to the sum of the two. If any two systems coincide with opposite phases,—the hollow of one striking the crest of another,—the height will be the difference of the two. Thus, if in two systems having the same wave-length and height, one is exactly half a length behind the other, they will destroy each other. This is termed he interference of waves. "In the port of Batsha, the tidal-vave comes up by two distinct channels, so unequal in length at their time of arrival varies by six hours. Consequently, hen the crest of high water reaches the harbor by one chan-

nel, it meets the low water returning by the other, and when these opposite phases are equal, they neutralize each other, so that at particular seasons there is no tide in the port, and at other times there is but one tide per day, and that equal to the difference between the ordinary morning and evening tide."—*Lloyd's Wave Theory.*

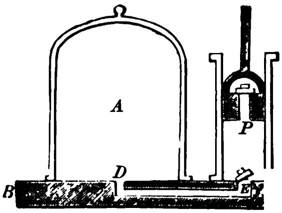
Another striking example of interference of tide-waves is seen in the immediate neighborhood of New York. The tide-wave from the ocean, coming from the south-east, divides, a part passing up New York Bay, and another part sweeping around and turning westward through Long Island Sound. The meeting-place of these two branches is at Hell Gate, the narrowest ship-channel between Long Island and New York. If a wall were built across Hell Gate, the water on one side would sometimes be five feet above that on the other. In the absence of such a wall, the current surges with great rapidity under the Brooklyn Bridge, alternately in opposite directions.

The manner in which different waves move among and upon one another, is seen by dropping a handful of stones in water and watching the waves as they circle out from the various centers in ever-widening curves. In Fig. 111 is shown the beautiful appearance these waves present when reflected from the sides of a vessel.

PNEUMATICS.

Pneumatics treats of the general properties and the pressure of gases. Since the molecules move among themselves more freely even than those of liquids, the conclusions which we have reached with regard to transmission of pressure, buoyancy, and specific gravity apply also to gases. Since air is the most abundant gas, it is taken as the type of the class, just as water is of liquids.

FIG. 112.



The Air-pump.

The air-pump is shown in its essential features in Fig. 11 *A is a glass receiver* standing on an oiled pump-plate. Th

tube D connecting the receiver with the cylinder, is closed by the valve E, opening upward. There is a second valve, P, in the piston, also opening upward. Suppose the piston is at the bottom and both valves shut. Let it now be raised, and a vacuum will be produced in the cylinder; the expansive force of the atmosphere in the receiver will open the valve E and drive the air through to fill this empty space. When the piston descends, the valve E will close, while the valve P will open, and the air will pass up above the piston. On elevating the piston a second time, this air is removed from the cylinder, while the air from the receiver passes through as before. At each stroke a portion of the atmosphere is drawn off; but the expansive force becomes less and less, until finally it is insufficient to lift the valves. For this reason a perfect vacuum can not be obtained.

The Air-pump.

The condenser, in construction, is the same as the air-pump, except that the valve opens inward instead of outward. Instead of exhausting, it forces more air into a vessel.

The Condenser.

The practical applications of this pump are numerous. The soda manufacturer uses it to condense carbonic acid in soda-water reservoirs.—The engineer employs it in laying the foundations of bridges. Large tubes or caissons are lowered to the bed of the stream, and air being forced in, drives out the water. The workmen are let into the caissons by a sort of trap, and work in this condensed atmosphere.—Pneumatic dispatch-tubes contain a kind of train holding the mail, and back of this a piston fitting the tube. Air is forced in behind the piston or exhausted before it, and so the train is driven through the tube at a high speed.—In the Westinghouse air-brake, condensed air is forced along a tube running underneath the cars, and by its elastic force drives the brakes against the wheel.

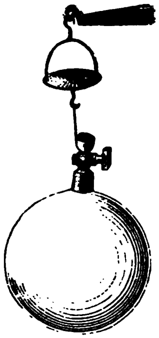
Properties of Air.

Weight.—Exhaust the air from a flask which holds 100 cubic inches, and then balance it. On turning the stop-cock, the air will rush in with a whizzing noise and the flask will descend (Fig. 113). It will require 31 grains or more to restore the equipoise.

Elasticity.—This is shown in a pop-gun. We compress the atmosphere in the barrel until the elastic force drives out

the stopper with a loud report. As we crowd down the piston we feel the elasticity of the air yielding to our strength, like a bent spring. — The bottle imps, or Cartesian divers, illustrate the same property. Fig. 114 represents a simple form of this apparatus. The cover of a fruit-jar is fitted with a tube, which is inserted in a syringe-bulb. The jar is filled with water and the diver placed within. This is a hollow image of glass, having a small opening at the end of the curved tail. If we squeeze the bulb, the air will be forced into the jar, and the water will transmit the pressure to the air in the image. This being compressed, more water will enter, and the diver, thus becoming heavier, will descend. On relaxing the grasp of the hand on the bulb, the air will return into it, the air in the image will expand, by its elastic force driving out the water, and the diver, thus lightened of his ballast, will ascend. The nearer the image is to the bottom, the less force will be required to move it. With a little care it can be made to respond to the slightest pressure, and will rise and fall as if instinct with life. Prick a hole in the small end of an egg, and place the egg with the big end up in a wine-glass. On exhausting the receiver, the bubble of air in the upper part of the egg will drive the contents *down into the* glass, and on admitting the air *they will be forced back* again.

FIG. 113.



Weighing Air.

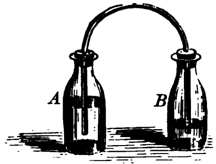
FIG. 114.

Cartesian Diver.

FIG. 115.

Expansibility of Air.

FIG. 116.



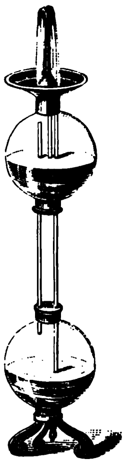
Transfer of Liquid under Receiver.

Expansibility. — Let a well-dried bladder be partly filled with air, and tightly closed. Place it under the receiver and exhaust the air. The air in the bladder expanding will burst it into shreds.

Take two bottles partly filled with colored water. Let a bent tube be inserted tightly in *A* and loosely in *B*. Place this apparatus under the receiver and exhaust the air. The expansive force of the air in *A* will drive the water over into *B*. On re-admitting the air into the receiver, the pressure will return the water into *A*. It may thus be driven from bottle to bottle at pleasure.

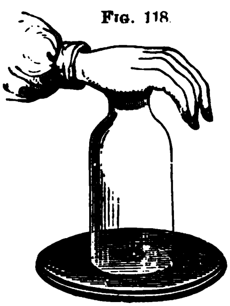
This experiment shows also the buoyant force of liquids, their transmission of pressure in every direction, and the increase of the pressure in proportion to the depth. The elasticity of the air, as well as the principles explained by the Cartesian diver (Fig. 114) may be illustrated in the following simple manner: Fill with water a wide-mouth 8-oz. bottle, and also a tiny vial, such as is used by homeopathists. Invert the vial and a few drops of water will run out. Now put it inverted into the bottle, and if it does not sink just below the surface and there float, take it out and add or remove a little water, as may be needed. When this result is reached, cork the bottle so that the cork touches the water. Any pressure on the cork will then be transmitted to the air in the vial, as in the image in Fig. 114.

FIG. 117.



Hiero's Fountain.

FIG. 118.



Hand-glass.

Hiero's fountain acts on the same principle, as may be seen by an examination of Fig. 117. Having removed the jet-tube, the upper globe is partly filled with water. The tube being then replaced, water is poured into the basin on top. The liquid runs down the *pipe at the right, into* the lower globe. The air in that globe

is driven up the tube at the left into the upper globe, and by its elasticity forces the water there out through the jet-tube, forming a tiny fountain.

If we cover a hand-glass with one hand, as in Fig. 118, on exhausting the air we shall find the pressure painful. The exhaustion of the air does not produce the pressure on the hand; it simply reveals it. The average pressure on each person is 16 tons. It is equal, however, on all parts of the body, and is counteracted by the air within. Hence we never notice it. Persons who go up high mountains or go down in diving-bells feel the change in the pressure.

Fig. 119.

Magdeburg Hemispheres.

Tie over one end of the glass a piece of wet bladder. When dry, exhaust the air, and the membrane will burst with a sharp report. To show the crushing force of the atmosphere, take a tin cylinder 15 inches long and 4 inches in diameter. Fit one end with a stop-cock for the exit of the steam. Put in a little water and boil. When the air is entirely driven out, turn the stop-cock. Pour cold water over the outside to condense the steam, when the cylinder will collapse as if struck by a heavy blow.

Fig. 120.

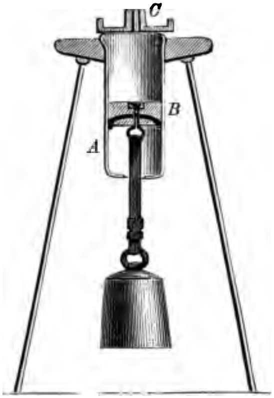
Water held up by Pressure of Air.

The Magdeburg Hemispheres are named from the city in which Guericke, their inventor, resided. They consist of two small brass hemispheres, which fit closely together, but may be separated at pleasure. If, however, the air be exhausted from within, several persons will be required to pull them apart. In whatever position the hemispheres are held, the pressure is the same.

In the museum at Berlin, the hemispheres used by Guericke in his experiments are preserved. They are of copper, and 22 inches interior diameter, with a flange an inch wide, making the entire diameter 2 feet. Accompanying is a Latin book b

the burgomaster describing numerous pneumatic experiments which he had performed, and containing a wood-cut representing three spans of horses on each side trying to separate the hemispheres.

Fig. 120a.



The Weight-lifter.

Fill a tumbler with water, and then lay a sheet of paper over the top. Quickly invert the glass, and the water will be supported by the upward pressure of the air.—Within the glass cylinder, Fig. 120*a*, is a piston working air-tight. Connect the nozzle above with the air-pump by means of a rubber tube and exhaust the air. The weight will leap up as if caught by a spring.

The law of Archimedes holds true in gases. A hollow sphere of glass or copper, Fig. 120*b*, is balanced in the air by a solid lead weight, but on being placed under the receiver it steadily falls while the air is becoming exhausted. This shows that its weight was partly sustained by the buoyant force of the air.

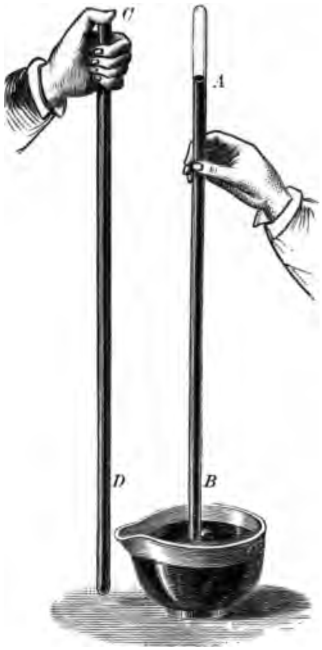
Fig. 12 *b*.

Buoyancy of Air.

At sea-level, the pressure of the air sustains a column of mercury 30 inches high, or of water nearly 34 feet high, and is nearly 15 lbs. per square inch. Take a strong glass tube about three feet in length, and tie over one end a piece of wet bladder. When dry, fill the tube with mercury, and invert it in a cup of the same liquid. The mercury will sink to a height of about 30 inches. If the area across the tube be one square inch, the metal will weigh about 14.7 lbs. The weight of the column of mercury is equal *to the downward pressure* on each square inch of the surface

of the mercury in the cup. Hence we conclude that the pressure of the atmosphere is 14.7 lbs. per square inch, and will balance a column of mercury 30 inches high. As water is 13½ times lighter than mercury, the same pressure would balance a column of that liquid 13½ times higher, or 33¾ feet.

FIG. 120*c*.



Torricelli's Experiment.

On account of the unwieldly length of the tube required to exhibit the column of water, it is not easy to verify this. It may, however, be prettily illustrated. Pour on the mercury in the cup, Fig. 120*c*, a little water colored with red ink. Then raise the end of the tube above the surface of the metal, but not above that of the water; this will rise in the tube, the mercury passing down in beautifully-beaded globules. The mercurial column is only 30 inches high, while the water will fill the tube. Finish the experiment by puncturing the bladder with a pin, when the water will instantly fall to the cup below.

Pressure of the Air Varies.

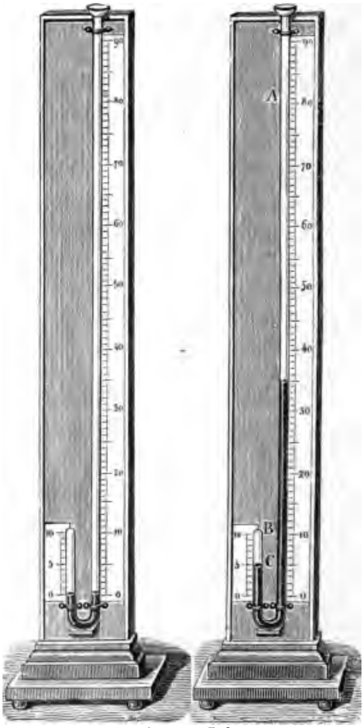
We live at the bottom of an aërial ocean whose depth is greater than that of the deepest sea. Its invisible currents surge round us on every side. Changes of temperature, moisture, etc., continually vary the density of the air, and change the height of the column of liquid it can support. The pressure also increases with the depth. Hence, in a valley the column of mercury stands higher than on a mountain. The pressure of the atmosphere is 29.92 inches only at the level of the sea, and at the temperature of melting ice at latitude 45°. The variation *due to latitude is very slight*; that due to temperature is greater.

and that due to elevation is greatest. Observations on the barometer at any given station are generally "reduced" to what they would be under the standard conditions just mentioned.

Mariotte's Law.*

Figure 121 represents a long, bent glass tube with the end of the short arm closed. Pour mercury into the long arm until it rises to the point marked zero. By cautiously inclining the apparatus, when a little air will escape, and adding more mercury if needed, the liquid can be made to stand at zero in both arms.

FIG. 121. FIG. 122.



Mariotte's Tube.

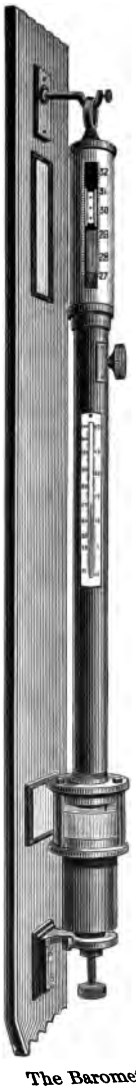
The air presses on the mercury in the long arm with a force equal to a column of mercury 30 inches high, and the elastic force of the air confined in the short arm is equal to the same amount. Now pour additional mercury into the long arm until it stands at 30 inches above that in the short arm (Fig. 122), and the pressure is doubled. In the short arm, the air is condensed to one half its former dimensions, and the elastic force is also doubled. We therefore conclude that the elasticity of a gas increases and the volume diminishes in proportion to the pressure upon it. The force with which the flying molecules of air beat against the walls of any confining vessel will increase with the diminution of the space through which

* This law was independently discovered by the Englishman, Boyle, ıd *the Frenchman*, Mariotte, during the latter part of the seventeenth ıtury. *It is often called* Boyle's Law.

they can pass. If we give them only half the distance to fly through, they will strike twice as often and exert twice the pressure.

The barometer is an instrument for measuring the pressure of the air. It consists essentially of the tube and cup of mercury in Fig. 123. A scale is attached for convenience of reference. The barometer is used (*a*) to indicate the weather, and (*b*) to measure the height of mountains.

Fig. 123.



The Barometer.

It does not directly foretell the weather. It simply shows the varying pressure of the air, from which we must draw our conclusions. A continued rise of the mercury indicates fair weather, and a continued fall, foul weather.

Mercury is used for filling the barometer because of its weight and low freezing-point. It is said that the first barometer was filled with water. The inventor, Otto von Guericke, erected a tall tube reaching from a cistern in the cellar up through the roof of his house. A wooden image was placed within the tube, floating upon the water. On fine days, this novel weather-prophet would rise above the roof-top and peep out upon the queer old gables of that ancient city, while in foul weather he would retire to the protection of the garret. The accuracy of these movements attracted the attention of the neighbors. Finally, becoming suspicious of Otto's piety, they accused him of being in league with the devil. So the offending philosopher relieved this wicked wooden man from longer dancing attendance upon the weather, and the staid old city was once more at peace.

Since the pressure diminishes above the level of the sea, the observer ascertains the fall of the mercury in the barometer, and the temperature by the thermometer; and then, by reference to tables, determines the height.

The Aneroid Barometer.

The action of this curious instrument depends upon the effect produced by atmospheric pressure upon a metallic box from which the air has been partially exhausted. Its appearance and construction are shown in Fig. 124.

Fig. 124.

An increased atmospheric pressure tends to force the cover inward; but when the atmospheric pressure diminishes it is pressed outward by its own elastic force, aided by a spring in the interior. The movements of the cover, transmitted by a combination of delicate levers, cause an index to move over a graduated scale.

Being very easily portable, this form of barometer has lately

Fig. 125.

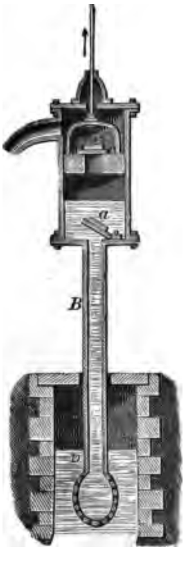


Fig. 126.

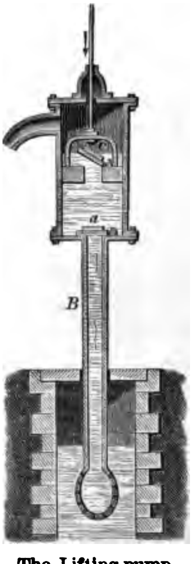
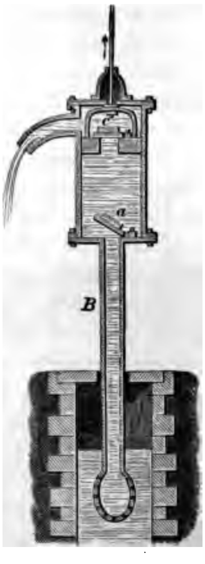


Fig. 127.



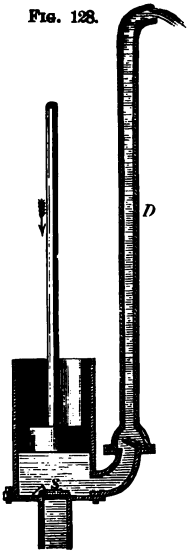
The Lifting-pump.

come into extensive use, especially for measuring the heights of mountains.

Instruments of this kind are now made that may be carried in the pocket like a watch, and they are so sensitive to slight changes of pressure that they will indicate a change of level of not more than three or four feet.

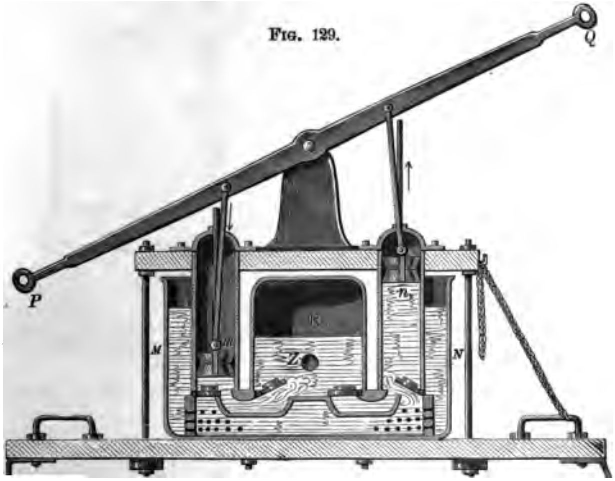
The lifting-pump contains two valves opening upward—one, *a*, at the top of the suction-pipe, *B*; the other, *c*, in the piston. Suppose the handle to be raised, the piston being at the bottom of the cylinder and both valves closed. Now depress the pump-handle and thereby elevate the piston. This will produce a partial vacuum in the suction-pipe. The pressure of the air on the surface of the water below will force the water up the pipe, open the valve, and partly fill the chamber. Let the pump-handle be elevated

FIG. 128.



Force pump.

FIG. 129.



Fire-engine.

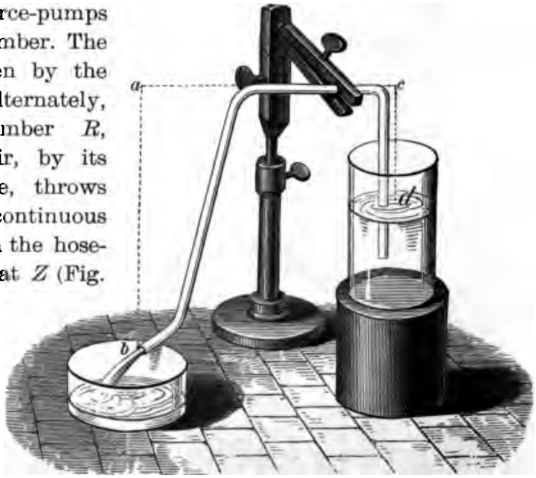
again, and the piston depressed. The valve *a* will then close, the valve *c* will open, and the water will rise above the piston (Fig. 126). When the pump-handle is lowered the second time and the piston elevated, the water is lifted up to the spout, whence it flows out; while at the same time the lower valve opens and the water is forced up from below by the pressure of the air (Fig. 127).

If the valves and piston were fitted air-tight, the water could be raised 34 feet (more exactly 13½ times the height of the barometric column) to the lower valve, but owing to various imperfections it commonly reaches about 28 feet. For a similar reason sometimes a dozen strokes are necessary to "bring water."

The force-pump has no valve in the piston. The water rises above the lower valve as in the lifting-pump. When the piston descends, the pressure opens the valve in the pipe *D*, and forces the water up. This pipe may be made of any length, and thus the water driven to any height.

The fire-engine consists of two force-pumps with an air-chamber. The water is driven by the pistons *m*, *n*, alternately, into the chamber *R*, whence the air, by its expansive force, throws it out in a continuous stream through the hose-pipe attached at *Z* (Fig. 129).

Fig. 130.



Siphon.

The siphon is a U-shaped tube, having one arm longer than the other. Insert the short arm in the water and then applying the mouth to the long arm, *exhaust the air.* The water will flow from the long arm until *the end of the short* arm is uncovered.

The Siphon.

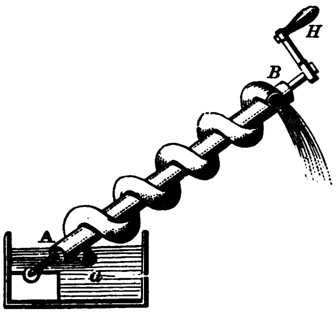
The pressure of the air at b holds up the column of water $a\ b$, and the upward pressure is the weight of the air less the weight of the column of water $a\ b$. The upward pressure at d is the weight of the air minus the weight of the column of water $c\ d$. Now $c\ d$ is less than $a\ b$, and the water in the tube is driven toward the longer arm by a force equal to the difference in the weight of the two arms.

The siphon is used more conveniently if two tubes of glass or metal are connected with a flexible tube of India rubber. An instructive experiment can then be made if we allow the water to run from one tumbler into another until just before the flow ceases; then quickly elevate the glass containing the long arm, carefully keeping both ends of the siphon under the water, when the flow will set back to the first tumbler. Thus we may alternate until we see that the water flows to the lower level, and ceases whenever it reaches the same level in both glasses. It will add to the beauty of this as well as of many other experiments, to color the water in one tumbler with a few scales of magenta, or with red ink.

FIG. 131.

Pneumatic Inkstand.

FIG. 132.



Archimedes' Screw.

The Pneumatic Inkstand.

The pneumatic inkstand can be filled only when tipped so that the nozzle is at the top. The pressure of the air will retain the ink when the stand is placed upright. When used below o, a bubble of air passes in, forcing the ink into the nozzle.

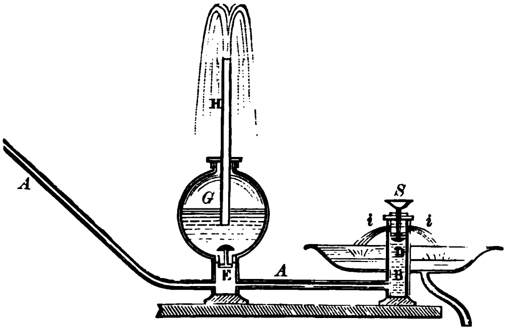
Archimedes' Screw.

The screw of Archimedes, invented by the *philosopher of that name,* is one of the most ancient contri-

ances for raising water. It was in use before the Christian era, and it is still used in Holland for draining low grounds.

As shown in Fig. 132, it consists of a tube wound in a spiral form around a solid cylinder, which is made to revolve by turning the handle, *H*. If placed at a proper inclination, the water, as the handle is turned, will continue to flow into those parts of the tube that are brought successively below the shaft till finally it will be discharged at the top.

FIG. 133.



Hydraulic Ram.

The Hydraulic Ram. The hydraulic ram is a machine for raising water where there is a slight fall. The water enters through the pipe *A*, fills the reservoir *B*, and lifts the valve *D*. As that closes, the shock raises the valve *E* and drives the water into the air-chamber *G*. *D* falls again as soon as an equilibrium is restored. A second shock follows, and more water is thrown into *G*. When the air in *G* is sufficiently condensed, its elastic force drives the water through the pipe *H*.

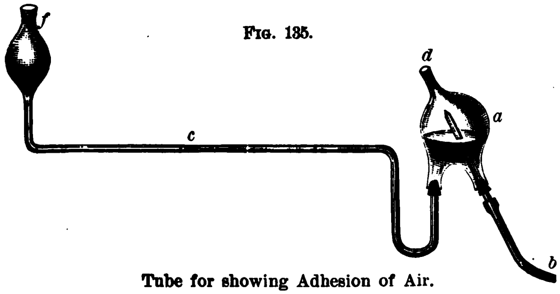
The Atomizer. The atomizer is used to turn a liquid into spray. The blast of air driven from the rubber bulb as it passes over the end of the upright tube, sweeps along the neighboring molecules of air and produces a partial vacuum in the tube. The pressure of the air in the bottle drives the liquid up the tube, and at the mouth the blast of air carries it off in fine drops. In locomotives, this principle

of the adhesion of gases to gases is applied to produce a draft. The waste steam is thrown into the smoke-pipe, and this current sweeps off the smoke from the fire, while the pressure of the atmosphere outside forces the air through the furnace and increases the combustion.—A familiar illustration may be devised by taking two disks of card-board, the lower one fitted with a quill, and the upper one merely kept from sliding off by a pin thrust through it and extending into the quill. The more forcibly air is driven through the quill against the upper disk, the more firmly it will be held to its place. See article "Ball Paradox," in *Popular Science Monthly*, April, 1877.—Faraday used to illustrate the principle thus: Hold the hand out flat with the fingers extended and pressed together. Place underneath a piece of paper two inches square. Blow through the opening between the index and the middle finger, and so long as the current is passing the paper will not fall.

FIG. 134.

Atomizer.

FIG. 135.



Tube for showing Adhesion of Air.

The action of a current of air in dragging along with it the adjacent still atmosphere and so tending to produce a vacuum, is shown by the apparatus represented in Fig. 135. A globe, *a*, is connected with a horizontal tube, c, containing col-

ored water. Close the opening *d* with the finger, and with the mouth at *b* draw the air out of the globe. A slight rarefaction will cause the liquid, by the pressure of the air at the opening *f*, to be forced into *a*. Now, if, instead of drawing the air out at *b*, a jet of air be forced through the tube and out at *d*, the same effect will be produced.

Height of the Atmosphere.

Three opposing forces act upon the air, viz.: gravity, which binds it to the earth; and the centrifugal and repellent forces, which tend to hurl it into space. There must be a point where these balance. At the height of 3.4 miles, the mercury in the barometer stands at 15 inches, indicating that half the atmosphere is within about 3½ miles of the earth's surface. Beyond a height of 40 miles, the quantity of air is too small to be perceptible in any way. In mountain-climbing, or ascending to a great height in a balloon, the voyager is apt to suffer on account of the decrease in density of the air. In 1862, Mr. Glaisher ascended nearly seven miles, and there fainted. His assistant was barely able to open the valve and cause the balloon to descend. If it were every-where as dense as it is at sea-level, the upper limit of our atmosphere would be about five miles high.

CHAPTER VI.

ON SOUND.

"SCIENCE ought to teach us to see the invisible as well as the visible in nature: to picture to our mind's eye those operations that entirely elude the eye of the body; to look at the very atoms of matter, in motion and in rest, and to follow them forth into the world of the senses."—TYNDALL.

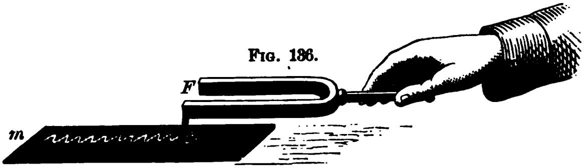
THE term sound is used in two senses—the subjective (which has reference to our mind) and the objective (which refers to the objects around us). 1st. Sound is the sensation produced upon the organ of hearing by vibrations in matter. In this use of the word there can be no sound where there is no ear to catch the vibrations.—An oak falls in the forest, and if there is no ear to hear it there is no noise, and the old tree drops quietly to its resting-place.—Niagara's flood poured over its rocky precipice for ages, but fell silently to the ground. There were the vibrations of earth and air, but there was no ear to receive them and translate them into sound. When the first foot trod the primeval solitude, and the ear felt the pulsations from the torrent, then the roaring cataract found a voice and broke its lasting silence. 2d. Sound consists of those vibrations of matter capable of producing a sensation upon the organ of hearing. In this use of the word there can be a sound in the absence of the ear. An object falls and the vibrations are produced, though there may be no organ of hearing to receive an impression from them. This is the sense in which the term sound is used in Physics.

Production of Sound.

By lightly tapping a glass fruit-dish, we can throw the sides into motion visible to the eye.—Fill a goblet half-full of water, and rub a wet finger lightly around the upper edge of the glass. The sides will vibrate, and cause tiny waves to ripple the surface of the water.—Hold a card close to the prongs of a vibrating

tuning-fork, and you can hear the repeated taps. Place the cheek near them, and you will feel the little puffs of wind. Insert the handle between your teeth, and you will experience the indescribable thrill of the swinging metal. The tuning-fork may

FIG. 136.



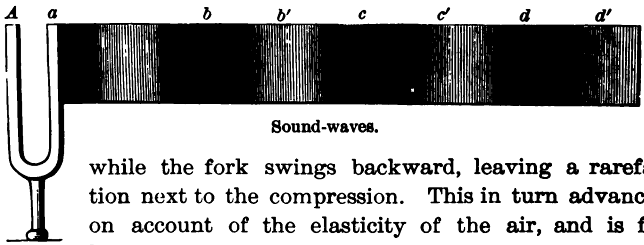
Tuning fork Registering its Vibrations.

be made to draw the outline of its vibrations upon a smoked glass. Fasten upon one prong a sharp point, and drawing the fork along, a sinuous line will show the width (amplitude) of the vibrations.

Transmission of Sound.

In order that any medium shall transmit sound, it must be elastic. Most known bodies possess some elasticity, and hence sound may be transmitted through gases, liquids, and solids. The prong of a tuning-fork advances, condensing the elastic air in front of it. This transmits the compression to the air next forward,

FIG. 137.



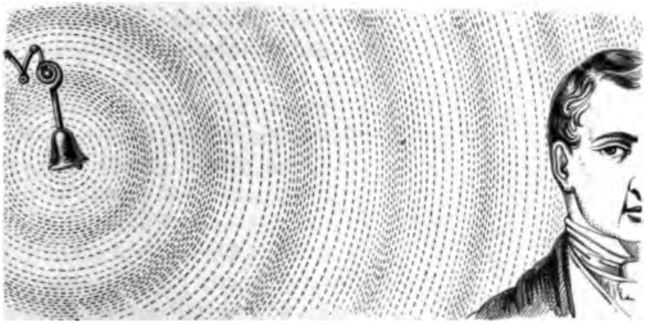
Sound-waves.

while the fork swings backward, leaving a rarefaction next to the compression. This in turn advances, on account of the elasticity of the air, and is followed by a compression due to the second forward swing of the fork. This process is repeated, until the fork comes to rest, and the sound ceases. Each vibration produces a sound-wave of air, which contains one condensation and one rarefaction. In water, we measure a wave-length from crest to crest; *in air, from* condensation to condensation. The condensation *of the* sound-wave corresponds to the crest, and the rare-

faction of the sound-wave to the hollow of the water-wave. In Fig. 137, the dark spaces *a*, *b*, *c*, *d* represent the condensations, and *a′*, *b′*, *c′* the rarefactions; the wave-lengths are the distances *ab*, *bc*, *cd*.

If we fire a gun, the gases which are produced expand suddenly and force the air outward in every direction. This hollow shell of condensed air imparts its motion to the next one, while it springs back by its elasticity and becomes rarefied. The second shell rushes forward with the motion received, then

FIG. 138.



Propagation of Sound.

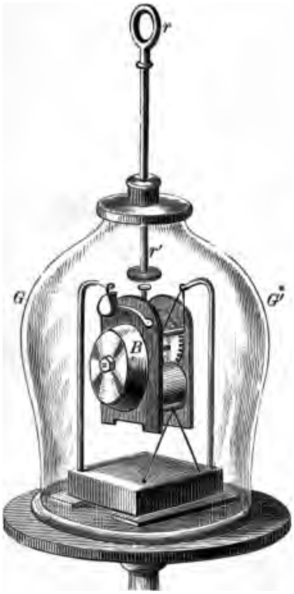
bounds back and becomes rarefied. Thus each shell of air takes up the motion and imparts it to the next. The wave, consisting of a condensation and a rarefaction, proceeds onward. It is, however, as in water-waves, a movement of the form only, while the particles vibrate but a short distance to and fro. The molecules in water-waves oscillate vertically; those in sound-waves horizontally, or parallel to the line of motion.

A continuous blast of air produces no sound. The rush of the grand aërial rivers above us we never hear. They flow on in the upper regions ceaselessly but silently. Let, however, the great billows strike a tree and wrench it from the ground, and we can hear the secondary, shorter waves which set out from the struggling limbs and the tossing leaves.

If a bell be rung, the adjacent air is set in motion; thence, by a series of condensations and rarefactions, the vibrations are

conveyed to the ear. "It is marvelous," says Youmans, "how slight an impulse throws a vast amount of air into motion. We can easily hear the song of a bird 500 feet above us. For its melody to reach us it must have filled with wave-pulsations a sphere of air 1,000 feet in diameter, or set in motion eighteen tons of the atmosphere."

FIG. 139.



Bell in Vacuum.

The bell *B* (Fig. 139) may be set in motion by the sliding-rod *r*. The apparatus is suspended by silk cords, that no vibration may be conducted through the pump. If the air be exhausted the sound will become so faint that it can not be heard, except when the ear is placed close to the receiver. There would be perfect silence in a perfect vacuum. No sound is transmitted to the earth from the regions of space. The movements of the heavenly bodies are noiseless.

In very elevated regions sounds are diminished in loudness, and it is difficult to carry on a conversation. The reverse takes place in deep mines and diving-bells.

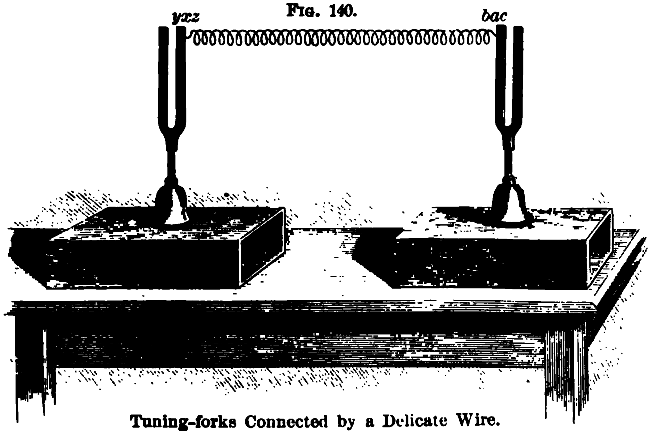
The ancients knew that without air we should be plunged in eternal silence. "What is the sound of the voice," cried Seneca, "but the concussion of the air by the shock of the tongue? What sound could be heard except by the elasticity of the aërial fluid? The noise of horns, trumpets, hydraulic organs, is not that explained by the elastic force of the air?"

Let two persons immerse themselves in water at a distance of twenty or thirty yards from each other. If one of them strikes two pebbles together, or rings a bell, the other will hear the sound with the utmost clearness.

The "Lovers' Telephone" consists of a pair of little cups, *the bottom of each* being made of an elastic substance, like

stretched bladder, and connected with that of the other by a string. By stretching the string elastic force is developed, and on talking into one of the cups the sound is readily heard at the other. On relaxing the string and thus diminishing the elasticity, sound ceases to be conveyed perceptibly by it. By putting the ear against the ground, one may hear the tread of footsteps that are inaudible through the air alone. Wheatstone invented a beautiful experiment to show the transmission of sound through wood. Upon the top of a music-box, he rested the end of a wooden rod reaching to the room above, and insulated from the ceiling by India rubber. A violin being placed on the top of the rod, the sounds from the box below filled the upper room, appearing to emanate from the violin.

FIG. 140.



Tuning-forks Connected by a Delicate Wire.

If a tuning-fork be excited and its stem be pressed firmly against a table, the sound will become much louder. The solid fork communicates its vibration to the table, which, in turn, gives its vibration to a much larger body of air than that in contact with the fork alone. Tuning-forks are generally mounted upon resonance boxes, the whole body of air within, as well as the box itself, thus co-vibrating with the fork.

The *air between any source* of sound and the ear is like an *elastic spring between a pair* of tuning-forks of the same size

and material. When the prong of the first fork swings from a to b (Fig. 140), a condensation is propagated through the spring and makes the prong of the second fork swing slightly from x toward y. A rarefaction follows, making it swing from x toward z. The succession of these properly-timed impulses causes an accumulation of energy to be imparted through the air to the second fork, which soon gives forth an audible sound. The elastic bodies composing the ear in like manner accept vibrations from outside, and their motion is perceived as sound.

The velocity of sound depends on the ratio of the elasticity to the density of the medium through which it passes. The higher the elasticity, the more promptly and rapidly the motion is transmitted, since the elastic force acts like a bent spring between the molecules; and the greater the density, the more molecules to be set in motion, and hence the slower the transmission.

Sound travels through air (at 32° F.) 1,090 feet per second. A rise in temperature diminishes the density of the air, and thus increases the velocity of sound. A difference of 1° F. makes a variation of a little more than one foot. Sound also moves faster in damp than in dry air.

Sound travels through water about 4,700 feet per second. This fact was established in 1826, by Colladon and Sturm, by a series of experiments at Lake Geneva, in Switzerland.

Velocity of Sound in Liquids.

Their method of ascertaining the fact was by the following experiment: Two boats were moored at a distance of nearly nine miles from each other. One of them supported a bell of about 140 pounds weight immersed in the lake. Its hammer was moved by a lever so arranged that, at the instant of striking the bell, it ignited a small quantity of gunpowder. An observer in the other boat heard the sound by means of a trumpet-shaped tube (Fig. 141), the lower end of which was covered with a membrane, and turned in the direction from which the sound came.

Water being denser than air, should on this account conduct sound more slowly; but its high elasticity, measured by the *amount of force* required to compress it, more than quadruples *the rate.*

By observing the interval between seeing the flash and hearing the sound, the velocity was found to be about 4,700 feet in a second, which is more than four times its velocity in air.

Fig. 141.

Sound travels through solids faster than through air. This may be illustrated by placing the ear close to the horizontal bar at one end of an iron fence, while a person strikes a sharp blow at the other end. Two sounds will reach the ear—one through the metal, and afterward another through the air. The velocity varies with the nature of the solid. In the metals it is from four to sixteen times that in air.

Different sounds travel with sensibly the same velocity. It has been said that the "heaviest thunder travels no faster than the softest whisper." Mallett, however, found that in blasting with a charge of 2,000 lbs., the velocity was 967 feet per second, while with 12,000 lbs. it was increased to 1,210 feet. Parry in his Arctic travels states that, on a certain occasion, the sound of the sunset-gun reached his ears before the officer's word of command to fire, proving that the report of the cannon traveled sensibly faster than the sound of the voice.

A band may be playing at a distance, yet the harmony of the different instruments is preserved. The soft and the loud, the high and the low notes reach the ear at the same time.

Light travels instantaneously so far as all distances on the earth are concerned. Sound moves more slowly. We see a chopper strike with his ax, and a moment elapses before we hear the blow. If one second intervenes, the distance is about 1,090 feet. By means of the second-hand of a watch or the beating of our pulse, we can count the seconds that elapse between a flash of lightning and the peal of thunder which follows. Multiplying the velocity of sound by the number of seconds, we obtain the distance of the thunder-bolt.

The loudness of sound depends chiefly on the amplitude of the vibration, if the air be quiet. The energy of the vibration *is proportional to the square* of the amplitude, i. e., the *arc through which the molecule* swings to either side of its position

of rest. But loudness is a sensation, and no accurate measurement of sensations has yet been made. The loudness of sound depends also on the density of the air. On the top of a mountain, because of the rare atmosphere, there are fewer molecules to be set in motion, hence the effect on the ear is less intense.

Mechanically considered, the intensity of sound diminishes as the square of the distance increases. The same proportion obtains in gravitation, sound, light, and heat. We have seen how the motion of the common pendulum is due to the force of gravity, and reveals the Laws of Falling Bodies. Now we find that the pendulum, and even the principles of Reflected Motion and Momentum, are linked with the phenomena of sound. As we progress further, we shall find how Nature is thus interwoven every-where with proofs of a common plan and a common Author.

The sound-wave expands in the form of a sphere. The larger the sphere, the greater the number of air-particles to be set in motion, and the feebler their vibration. The surfaces of spheres are proportional to the squares of their radii; the radii of sound-spheres are their distances from the center of disturbance. Hence the force with which the molecules will strike the ear decreases as the square of our distance from the sounding body increases.

Speaking-tubes conduct sound to distant rooms because they prevent the waves from expanding and losing their intensity. Biot held a conversation through a Paris water-pipe, 3,120 feet long. He says that "it was so easy to be heard, that the only way not to be heard was not to speak at all."

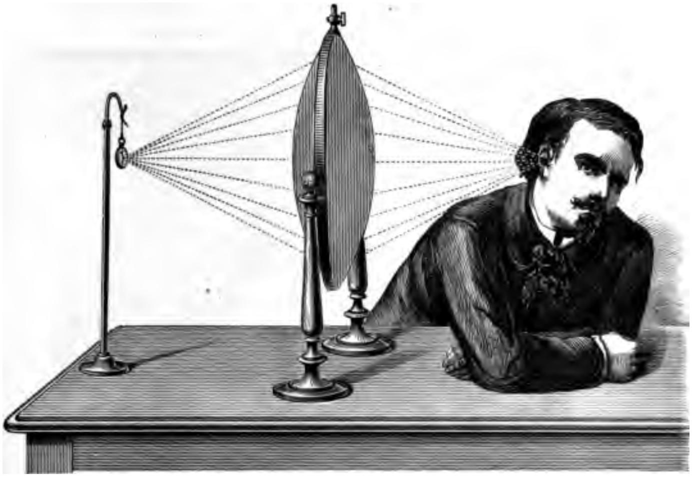
The ear-trumpet collects waves of sound and reflects them into the ear. The speaking-trumpet is based on the same principle as the speaking-tube. The sound of the voice is strengthened also by the co-vibration of the walls of the trumpet.

Refraction of Sound.

When a sound-wave goes obliquely from one medium to another, it is bent out of its course. This is called refraction. Like light, it may be passed through a lens and brought to a focus. In Fig. 142 is shown a bag of thin India rubber or collodion, filled with carbonic-acid gas so as to assume the form of a lens. A watch is placed at one focus of this and the ear at

the other. The ticks of the watch can be heard, while outside the focus they are inaudible.

Fig. 142



Refraction of Sound.

Reflection of Sound.

When a sound-wave strikes against the surface of another medium, a portion goes on while the rest is reflected.

The law of reflection of sound is the same as that of motion, namely: the angle of incidence is equal to that of reflection. Domes and curved walls reflect sound as mirrors do light. Thus, in the gallery under the dome of St. Paul's Cathedral, London, persons standing close to the wall can whisper to each other and be heard at a great distance. — Two persons, placed with their backs to each other, at the foci of an oval room, or "Whispering Gallery," can carry on a conversation that will be inaudible to spectators standing between them. — The covered recesses on the opposite sides of a street, or the arches of a stone bridge, oftentimes reflect sound so as to enable persons seated at the foci to converse in whispers while loud *noises are being* made in the open space between *these semi-domes.*

If the reflecting surface be very near, the reflected sound will join the direct one and strengthen it. This accounts for the well-known fact that a speaker can be heard more easily in a room than in the open air, and that a smooth wall back of

FIG. 143.

Reflection of Sound.

the stand re-enforces the voice. The old-fashioned "sounding-boards" were by no means inefficient, however singular may have been their appearance.

By revolving a disk of card-board from which a pair of sectors have been cut out, and blowing against it with a trumpet ɔr whistle, a person stationed at the proper angle will notice a *ɔeating sound* due to successive reflection and transmission of *ıe waves.*

Echoes are produced where the reflecting surface is so distant that we can distinguish the reflected from the direct sound. If the sound be short and quick, this requires at least fifty or sixty feet; but if it be an articulate one, as in ordinary speech, more than a hundred feet are necessary. It is possible to pronounce and hear distinctly about five syllables in a second; 1,120 ft. (the velocity at a medium temperature) $\div$ 5 = 224 ft. If the wave travel 224 feet in going and returning, the advancing and returning sounds will not blend, and the ear will be able to detect an interval between them. A person speaking in a loud voice squarely in front of a large smooth wall 112 feet distant, can distinguish the echo of the last syllable he utters; at 224 feet, the last two syllables, etc.

When several parallel surfaces are properly situated, the echo may be repeated backward and forward in a surprising manner. In Princeton, Ind., there is an echo between two buildings that will return the word "Knickerbocker" twenty times. So many persons visited the place that the city council forbade the use of the echo after 9 o'clock at night.—At Woodstock, England, an echo returns seventeen syllables by day and twenty by night. The reflecting surface is distant about 2,300 feet, and a sharp *ha!* will come back a ringing *ha, ha, ha!*—The echo is often softened, as in the Alpine regions, where it warbles a beautiful accompaniment to the shepherd's horn.—The celebrated echo of the Metelli at Rome is said to have been capable of distinctly repeating the first line of the Æneid eight times.—In Fairfax County, Va., is an echo which will return twenty notes played on a flute.—The tick of a watch may be heard from one end of the Church of St. Albans to the other.—At Carisbrook Castle, Isle of Wight, is a well 210 feet deep and twelve feet wide, lined with smooth masonry. When a pin is dropped into the well it is distinctly heard to strike the water. —In certain parts of the Colosseum at London, the tearing of paper sounds like the patter of hail, while a single exclamation comes back a peal of laughter.—The dome of the Baptistery of the Cathedral at Pisa has a wonderful echo. During some experiments there, the author found every noise, even the rattle of benches on the pavement below, to be reflected back as i from an immense distance and to return mellowed and softened

into music.—An interesting illustration of the reflection of sound is found at the so-called Echo River, of the Mammoth Cave, Ky. Sounding in succession the notes G, E, C, at the middle of the tunnel, the boatman receives the echoes, all mingled into a full chord, for eight or ten seconds afterward.

If we strike the bell, represented in Fig. 143, before a vacuum is produced, we shall find a marked difference between its sound under the glass receiver and in the open air resulting from reflection. Floors are deadened with tan-bark or mortar, since as the sound-wave passes from particle to particle of the unhomogeneous mass, it becomes weakened by partial reflection. The air at night is more homogeneous, and hence sounds are heard farther and more clearly than in the day-time.

Acoustic clouds* are masses of moist air of varying density, which act upon sounds as common clouds do upon light, wasting it by repeated reflections. They may exist in the clearest weather. To their presence is to be attributed the variation often noticed in the distance at which well-known sounds, as the ringing of church bells, blowing of engine-whistles, etc., are heard at different times. The extinction of sound by such agencies is often almost incredible. Thus two observers looking across the valley of the Chickahominy at the battle of Gaines' Mill failed to hear a sound of the conflict, though they could clearly see the lines of soldiers, the batteries, and the flash of the guns.—These phenomena are ascribed by many to an elevation or a depression of the wave-front so that the sound passes above the observer or is stopped before it reaches him

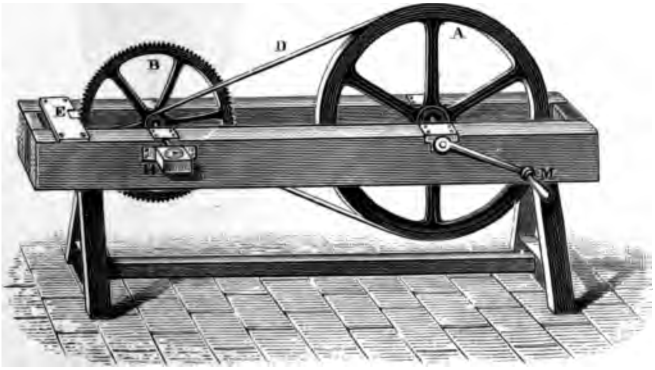
Musical Sounds.

The difference between noise and music is that between irregular and regular vibrations. Whatever the cause which sets the air in motion, if the vibrations are uniform and rapid enough, the sound is musical. If the ticks of a watch could be made with sufficient rapidity, they would lose their individuality and blend into a musical tone. If the puffs of a locomotive could reach fifty or sixty a second, its approach would be heralded by a tremendous organ-peal.

* *Tyndall has investigated the causes modifying the propagation of sound, as acoustic* clouds, fogs, etc., and popularized the whole subject of *acoustics.*

The pavement of London is largely composed of granite blocks, four inches in width. A cab-wheel jolting over this at the rate of eight miles per hour produces a succession of thirty-five sounds per second. These link themselves into a soft, deep musical tone, that will bear comparison with notes derived from more sentimental sources, even though it may seem confused to a hearer in its midst. This tendency of Nature to music is something wonderful. "Even friction," says Tyndall, "is rhythmic." A bullet flying through the air sings softly as a bird. The limbs and leaves of trees murmur as they sway in the breeze. Falling water, singing birds, sighing winds, every-where attest that the same Divine love of the beautiful which causes the rivers to wind through the landscape, the trees to bend in a graceful curve—the line of beauty—and the rarest flowers to bud and blossom where no eye save His may see them, delights also in the anthem of praise which Nature sings for His ear alone.

FIG. 144.



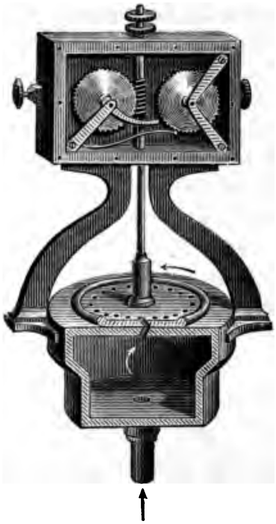
Pitch of Sounds.

Pitch, the degree of elevation of a sound, depends on the rapidity of vibrations. To illustrate by a simple experiment, if we hold a card against the cogs of a rapidly-revolving wheel, we shall obtain a clear tone; and the faster the wheel turns, the shriller will be the tone produced, *i. e.*, the higher will be the pitch. This is shown in Fig. 144.

The number of vibrations per second* is determined by an instrument called the siren. It consists of a cylindrical box (Figs. 145 and 146), the top of which is pierced with a series of holes. Over this is a plate with a corresponding series, fixed to

Fig. 145.

Fig. 146.



The Siren.

a vertical rod, which is pivoted on the lower plate so as to revolve easily. It is provided with an endless screw (Fig. 146), which operates some clock-work. On the dial (Fig. 145), we can see the number of turns made by the upper disk. The holes in the two disks are oppositely inclined, so that when a current of air is forced in from below it passes up through the openings in the lower disk, and striking against the sides of those in the

* The present century has witnessed a more complete demonstration of the laws of the vibrations of cords and the general principles of sound. In 1822, Arago, Gay-Lussac, and others decided the velocity of sound to be 337 meters at 10° C. Savart invented a toothed wheel by which he determined the number of vibrations in a given sound. Latour invented the siren, which gave still more accurate results.

upper disk, causes it to revolve. As that turns, it alternately opens and closes the orifices in the lower disk, and thus converts the steady stream of air into uniform puffs. At first, they succeed each other so slowly that they may be counted. But, as the motion increases, they link themselves together, and pass into a full, melodious note. As the velocity augments, the pitch rises, until the music becomes painfully shrill. Diminish the speed, and the pitch falls.

To find, therefore, the number of vibrations in a given sound, force the air through the siren until the required pitch is reached. See on the dial, at the end of a minute, the number of revolutions of the disk. Suppose the number of holes in a disk to be 10, and the tone produced to be in unison with that of a C_3 tuning-fork. The number of revolutions indicated on the dial at the end of a minute is found to be 1,536. There were 10 puffs, or 10 waves of sound, for each revolution. $1{,}536 \times 10 = 15{,}360$. Dividing this by 60, we have 256, the number per second. Increasing now the blast until the tone produced is in unison with a C_4 tuning-fork, the octave above the first, the number of vibrations per second is found to be 512. Hence the octave of a tone is caused by double the number of vibrations.

Suppose the air in the last experiment was of such a temperature that the foremost sound-wave traveled 1,120 feet in a second. In that space, there were 256 sound-waves. Dividing 1,120 by 256, we have $4\frac{3}{8}$ ft. as the length of each. We thus find the wave-length by dividing the velocity by the number of vibrations per second. As the pitch is elevated by rapidity of vibration, we perceive that the low tones in music are produced by the long waves and the high tones by the short ones.

The aërial waves are seemingly shortened when the source of sound is approaching, whether by its own motion or the hearer's, and lengthened when it is receding. In the former case, the tone of the sound is more acute; in the latter, graver. This is strikingly illustrated when a swift train rushes past a station, the whistle blowing. While the cars are approaching, a person hears a note somewhat sharper; after they have passed, one somewhat flatter than the true note. Still more obvious is the change when two trains pass each other. A person unfamiliar

with the arrangement would suppose a different bell was rung. In one case more and in the other fewer waves reach the ears in a second.

If the string of a violin, the cord of a guitar, the parchment of a drum, and the pipe of an organ, produce the same

FIG. 147.

Tube for Interference of Sound.

tone, it is because they are executing the same number of vibrations per second. The tones are then said to be in unison. If a voice and a piano perform the same music, the steel strings of the piano and the vocal cords of the singer vibrate together and send out sound-waves of the same length.

Just as two water-waves by meeting in opposite phases *may destroy one* another, so by a proper adjustment two sound-

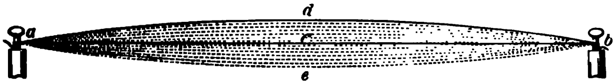
waves may be made to interfere, and, if exactly equal and opposite, to produce silence. Fig. 147 represents a piece of apparatus intended to show this. Let a tone, such as C_3, be sounded in the mouth-piece at *a*. The waves divide at the end of the first India-rubber tube and reunite on entering the second, before entering the ear at *b*. One branch of the channel is made of two tubes, one of which slides over the other so that the branch may be lengthened at will. If it be pulled up so high that the waves passing through it shall traverse a half wave-length more in distance than those in the fixed branch, opposite phases will meet where they reunite, and the listener notices great weakening of the sound. By proper handling, the sound received may be made to become alternately strong and weak without any change in the sound given.

Interference of Sound-waves.

We can not produce complete extinction because, 1. The sound is conducted not only by the inclosed air, but by the solid tube also; 2. There is loss by friction in the longer branch; 3. There is loss by leakage between the tubes that slide against each other.

If we strike a tuning-fork and turn it slowly around before the ear, we shall find four points where the interference of the sound-waves causes great weakening. The two prongs swing alternately toward and from each other. When a condensation is produced between the prongs, a rarefaction is produced on their outer sides. Certain lines can be found where these interfere.

FIG. 148.



Vibrating Cord.

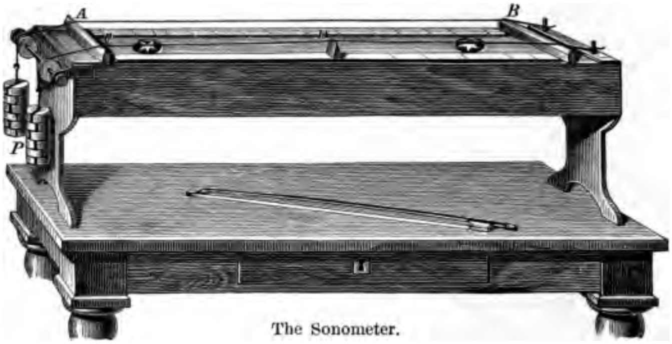
If two forks are nearly but not quite in unison, the waves from them are unequal in length. They alternately conjoin and oppose one another, producing "beats." These are often noticed in the sound from a large bell, the opposite sides of which are not quite equally elastic. A pair of mistuned organ-pipes produces a similar effect, and the discord of an inferior piano, or indeed all discord, is due to beats.

Vibrations of Cords.

Let ab be a stretched cord made to vibrate. The motion from e to d and back again is termed a vibration; that from e to d, a half-vibration. The distance, cd, from the middle to either of the extreme positions is the amplitude.

The sonometer is an instrument used to investigate the laws of vibration of stretched cords. It consists of two cords stretched by weights, P, across fixed bridges, A and B. The movable

FIG. 149.



The Sonometer.

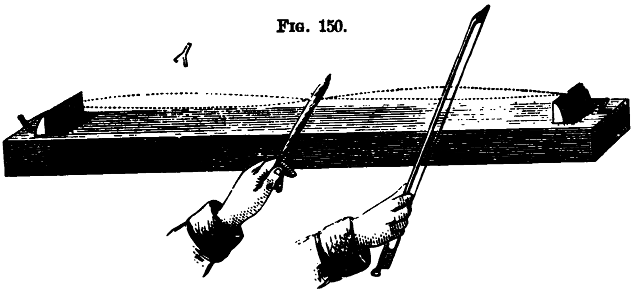
bridge, D, serves to lengthen or shorten the vibrating part of either cord. Beneath is a resonance box, to which the vibrations are conducted by the bridges. This is the body whose sound is chiefly heard.

Pythagoras, who lived in the sixth century before Christ, conceived that the celestial spheres are separated from each other by intervals corresponding with the relative lengths of strings arranged to produce harmonious tones. In his musical investigations he used a monochord, the original of the sonometer now employed by physicists, and wished that instrument to be engraved on his tomb. Pythagoras held that the musical intervals depend on mathematics; while his great rival, Aristoxenes, claimed that they should be tested by the ear alone. The theories of these two philosophers long divided the attention of the scientific world. The former considered the subject from the stand-point of Physics, the latter from that of Physiology.

The number of vibrations per second increases as the length of the cord decreases. By plucking the cord with the finger, or drawing a violin bow across it, make it vibrate, giving the note of the entire string. Place the bridge *D* at the center of the cord, and the sound will be the octave above the former. Thus, by taking one half the length of the cord we double the number of vibrations. If an entire cord make 20 vibrations per second, one half will make 40, and one third, 60.—The violin or guitar player elevates the pitch of a string by moving his finger, thus shortening the vibrating portion.—In the piano, harp, etc., the long and the short strings produce the low and the high notes respectively.

The number of vibrations per second increases as the square root of the tension. The cord when stretched by 1 lb. gives a certain tone. To double the number of vibrations and obtain

FIG. 150.



Production of two Segments.

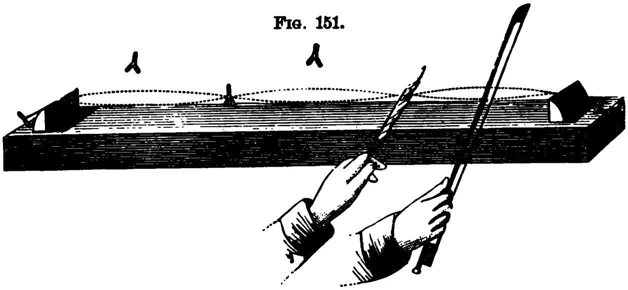
the octave requires 4 lbs. Stringed instruments are provided with keys, by which the tension of the cord and the corresponding pitch may be increased or diminished.

The number of vibrations per second decreases as the square root of the weight of the cord increases. If two strings of the same material be equally stretched, and one have four times the weight of the other, it will vibrate only half as often. In the violin, the bass notes are produced by the thick strings. In the piano, fine wire is coiled around the heavy strings to increase their weight.

In the *experiments just* described, the cord is shortened by *means of a firm, movable* bridge. If, instead, we rest a feather

lightly on the string, and draw the bow over one half, the cord will vibrate in two portions, and give the octave as before. Remove the feather, and it will continue to vibrate in two parts, and to yield the same tone. We can show that the second half vibrates by placing across that portion a little paper rider. On

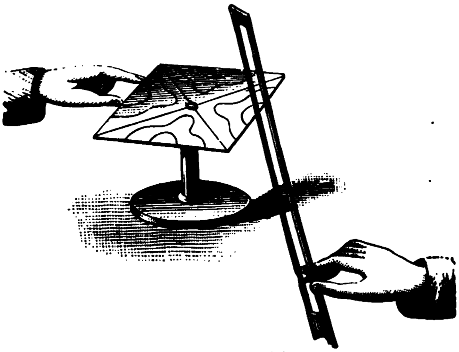
FIG. 151.



Production of Three Segments.

drawing the bow it will be thrown off. Hold the feather so as to separate one third of the string and cause it to vibrate; the remainder of the cord will vibrate in two segments. When the feather is removed, the entire cord will vibrate in three different parts of equal length, separated by stationary points called nodes. This may be shown by the riders; the one at the node remains, while the others are thrown off.

FIG. 152.

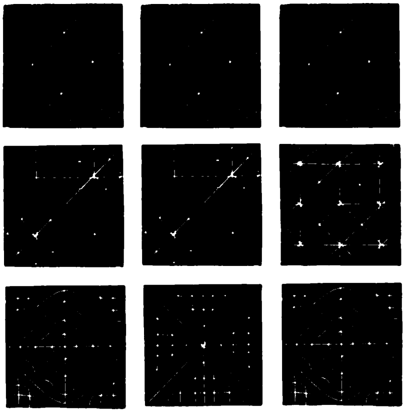


Vibration of a Plate.

Sprinkle fine sand on a metal plate. Place the finger-nail on one edge to stop the vibration at that point, as the feather *did in the last* experiment, and draw the bow lightly across the *opposite edge*. The sand will be tossed away from the vibrat-

ing parts of the plate, and will collect along the nodal lines, which divide the large square. It is wonderful to see how the sand will seemingly start into life and dance into line at the touch of the bow. Fig. 153 shows some of the beautiful patterns obtained by Chladni. These figures are called Acoustic Figures.

Fig. 153.



Chladni s Figures.

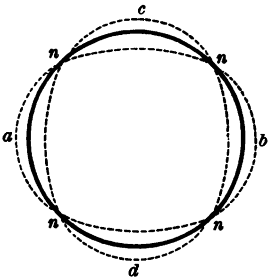
Whenever a cord vibrates, it separates into segments at the same time. Thus we have the full or fundamental note of the entire string, and superposed upon it the higher notes produced by the vibrating parts. These are called overtones or harmonics. The mingling of the two classes of vibrations determines the quality of the sound, and enables us to distinguish the music of different instruments. Press gently but firmly down the notes C, G, and C, in the octave above middle C, on the piano-forte. Without releasing these keys, give to C below middle C a quick, hard blow. The damper will fall, and the sound will stop abruptly. At the same instant a low, soft chord will be heard. This comes from the three strings whose dampers are raised, leaving them free to sound in sympathy with the overtones of the lower C, which sounds are identical with their own.— When a goblet or wine-glass is tapped with a knife-blade, we can distinguish three sounds, the fundamental and two harmonics.*

Let the heavy circle in Fig. 154 represent the circumference of a bell when at rest. Let the hammer strike at *a*, *b*, *c*, or *d*. At one moment, as the bell vibrates, it forms an oval with *ab*, at the next with *cd*, for its longest diameter. When it strikes

* *Helmholtz made* known the laws of harmonics.

its deepest note, the bell vibrates in four segments, with *n*, *n*, *n*, *n*, as the nodal points, whence nodal lines run up from the edge to the crown of the bell. It tends, however, to divide into a greater number of segments, especially if it is very thin, and to produce harmonics. The overtones which accompany the deep tones of the bell are frequently very striking, even in a common call-bell, and often make it hard to determine at once what is its fundamental. Usually they die away sooner than the fundamental.

Fig. 154.



Vibration of a Bell.

The case of a violin or guitar is composed of thin wooden plates which divide into vibrating segments, separated by nodal lines according to the pitch of the note played. The inclosed air vibrating in unison with these, re-enforces the sound and gives it fullness and richness.

The lowest tone that can be distinctly perceived as musical by most ears is produced by 32 vibrations per second. This is called C_0. The octave above this is C_1, 64 vibrations; the double octave, C_2, 128 vibrations, etc. If a string be stretched so as to give C_2, the tones of the common musical scale between this and C_3 are obtained from the parts of the string indicated by the following fractions:

C_2	D_2	E_2	F_2	G_2	A_2	B_2	C_3
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

These notes form what is called a musical scale. As the number of vibrations varies inversely as the length of the cord, we have only to invert these fractions to obtain the relative number of vibrations per second; thus:

C_2	D_2	E_2	F_2	G_2	A_2	B_2	C_3
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
128	144	160	170	192	214	240	256

In this table, "$C_3 = 256$ vibrations" represents the middle C *of a piano-forte.* This number is purely arbitrary. The so-

called "concert-pitch" varies in different countries. The Stuttgart Congress of 1834 fixed the standard tuning-fork—middle A —at 440 vibrations per second, which would make middle C = 264; while the Paris Conservatory (1859) gave to middle A 437.5, and to middle C 261. The common English tuning-fork represents C_4, and makes 528 vibrations, the pitch being the same as the Stuttgart. The ratio of the different numbers is identical, whatever the pitch.

Vibration of Columns of Air.

If a tuning-fork be excited and its prongs be held before the open end of a tube of proper length, the sound will become much louder, resulting from the vibration of the column of air. If the pitch of the fork is C_4, 512 vibrations, the length of such a tube, open at both ends, is about 13 inches; if open at only one end, 6½ inches. A hollow globe of proper size, with an opening on one side, will respond in like manner. Such bodies are called *resonators*.

Wind Instruments.

Wind instruments produce sounds by the vibration of the columns of air which they inclose. An organ-pipe is merely a tube-resonator. The sound-waves in organ-pipes are set in motion by either fixed mouth-pieces or vibrating reeds. The air is forced from the bellows into the tube *P*, through the vent *i*, and striking against the thin edge *a*, produces a flutter. The column of air above, thrown into vibration, re-enforces the sound and gives a full musical tone. The length of the pipe, if open, should be ½ wave length corresponding to the pitch to which it responds; if closed, ¼ wave length. If a tuning-fork which produces this pitch be held at *b* while vibrating, the sound will at once become much stronger. The air co-vibrates, whatever may be the source of sound, if only the pitch be properly adjusted.

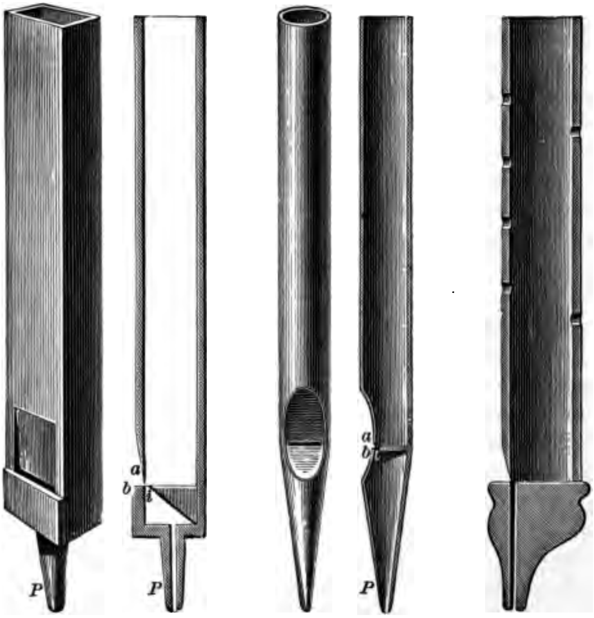
Co-vibration.

We have already seen how one tuning-fork may co-vibrate with another through the medium of the air. Vibrations thus produced are often called sympathetic, and bodies which thus strengthen sound are said to be resonant. Produce a musical tone with the voice near a piano, and a certain wire will seem to select that sound and respond to it. Change the pitch, and the first string will cease, while another replies. If a hundred tuning-forks of different tones are sounding at the foot of an organ-pipe, it will

strengthen the sound of the one to which it can reply, and answer that alone. Helmholtz has applied this principle to the construction of the resonance globe, an instrument which will respond to a particular harmonic in a compound tone, and strengthen it so as to make it audible.

Galileo gave an accurate explanation of the phenomena of resonance, and referred to the fact that every pendulum has a

FIG. 155.



Organ-pipes.

fixed oscillation period of its own; that a succession of properly timed small impulses may throw a heavy pendulum into vibration, and that this may communicate vibration to a second pendulum of the same vibration period. Galileo also described the first experiment involving the direct determination of a vibration atio for a known musical interval. He related that he was one ay *engaged in* scraping a brass plate with an iron chisel, in der *to remove* some spots from it, and noticed that the pas-

sage of the chisel across the plate was sometimes accompanied by a shrill whistling sound. On looking closely at the plate, he found that the chisel had left on its surface a long row of indentations parallel to each other and separated by exactly equal intervals. This occurred only when a sound was heard. It was found that a rapid passage of it gave rise to a more acute sound, a slower passage to a graver sound, and that in the former case the indentations were closer together. After many trials, two sets of markings were obtained, which corresponded to a pair of tones making an exact fifth with each other. The indentations were 30 and 45, respectively, to a given length. Galileo's inference from this was exactly what we now accept as true.

Fig. 156.

Singing Flame.

Flames are sensitive to sound. At an instrumental concert the gas-lights vibrate with certain pulsations of the music. This is noticeable when the pressure of gas is so great that the flame is just on the verge of flaring, and the vibration of the sound-wave is sufficient to "push it over the precipice."

Prof. Barrett, of Dublin, describes a peculiar jet which is so sensitive that it trembles and cowers at a hiss, like a human being, beats time to the ticking of a watch, and is violently agitated by the rumpling of a silk dress.

If we lower a glass tube over a small gas-jet, we soon reach

a point where the flame leaps spontaneously into song. At first the sound seems remote, but gradually approaches until it bursts into an almost full song. The length of the tube and the size of the jet determine the pitch of the note.

The jets are easily made by drawing out glass tubing to a fine point over a spirit-lamp.

The flame, owing to the friction at the mouth of the pipe, is thrown into vibration. The air vibrates in unison with the jet, and, like that in the organ-pipe, selects the tone corresponding to the length of the tube.

The Phonograph.

The phonograph is an instrument for recording and reproducing the vibrations of sound. Its essential features are as follows:

A metallic cylinder which can be rotated on a screw as axis, so as to secure motion that is sideward as well as rotary.

A hollow cylinder of wax which fits over the metallic cylinder, and may be removed after receiving impressions from a source of sound.

A mouth-piece into which the speaker vocalizes. At the bottom of this is an elastic disk, which is set into vibration by the voice.

A lever which is actuated by the disk. At one end of it is a specially prepared needle, which makes indentations upon the rotating cylinder of wax.

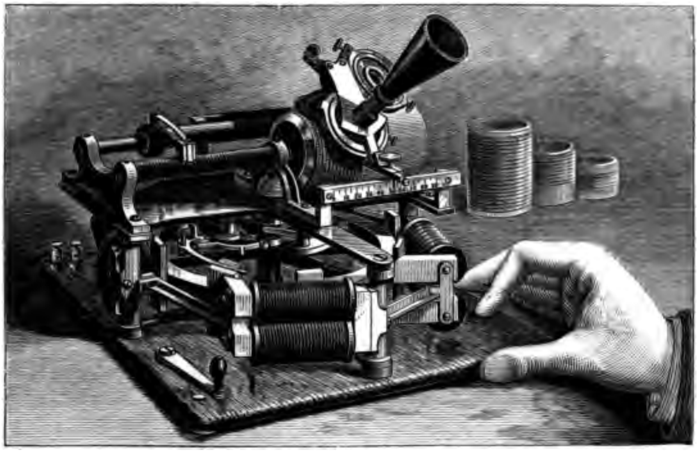
After the line of indentations has been made on the wax, the cylinder is brought back to its first position. On turning it, the needle, pressing on the serrated surface, receives vibratory motion like that which had been given it by the voice. This is received by the disk, and the instrument thus talks out what had been talked into it.

There are usually two mouth-pieces, interchangeable in position, one of which is used in speaking to the phonograph, and the other in giving out what this has to say. Each is specially adapted to the work it has to do. The metallic cylinder is rotated by means of an electric motor. The arm which carries the mouth-pieces is provided with a turning tool for smoothing the wax before this receives the record from the voice.

In Fig. 157, the phonograph is shown ready to talk. A

conical speaking-trumpet is fixed upon the mouth-piece, so that the sound may be strengthened by co-vibration. The wax cylinder can be kept any length of time, and be made to speak out its message repeatedly. The phonograph reproduces so accurately the sounds it has received, that even the peculiarities

Fig. 157.



The Phonograph.

which result from the special quality of the speaker's voice can be recognized.

The Human Voice.

The most perfect reed instrument is the human voice. Across the top of the trachea, or windpipe, are stretched two elastic bands, called vocal cords; through the space between the cords the air passes in and out of the lungs.

During speaking and singing the space between the cords is less than in ordinary breathing. The voice is produced by the air, which, driven from the lungs and striking against the cords, causes them to vibrate. The greater the tension of the cords the higher the pitch.

The mouth, by its resonance, re-inforces the sound given out by the cords. By change of shape it can be made to resound to the fundamental tone, or any of the overtones of the vocal cords.

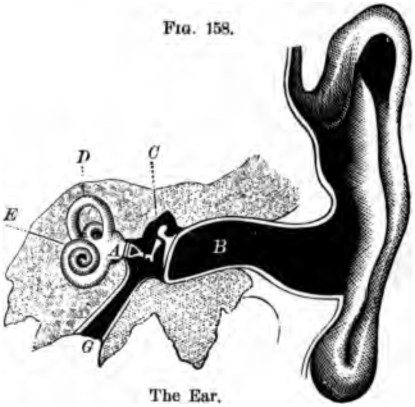
The Human Ear.

The human ear is also an instrument for receiving sound vibrations, which affect the auditory nerve and produce sensation thus at the base of the brain.

A section of the ear is seen in Fig. 158. It consists of the external ear, so formed as to enable it to catch the sound-waves. *B* represents the auditory canal, about an inch in length. A circular membrane, called the membrane of the tympanum, closes the lower end of it.

The drum of the ear, or the tympanum, is the cavity behind this membrane. Beyond the drum is the labyrinth. It consists

Fig. 158.



The Ear.

of a small rounded chamber, *A*, called the vestibule; from it open three semicircular canals, *D*, and a spiral canal, *E*, called the cochlea, from its resemblance to a snail-shell.

Through these canals the auditory nerve is distributed. From the membrane of the tympanum to the membrane of the vestibule a chain of three bones is stretched, the hammer attached to the membrane of the tympanum, the anvil, and the stirrup connected with the membrane of the vestibule. The vibrations of the atmosphere strike against the membrane of the tympanum, and are conducted through the chain of bones to the second membrane, and thence, by the auditory nerve, to the brain. The Eustachian tube, *G*, admits air to the drum, and thus keeps the density within the same as the external air.

No definite limit can be assigned to the range through which musical sounds are perceptible. The highest limit has been roughly estimated to be about 38,000, and the lowest, 16, vibrations per second. When the number of impressions on the ear in each second is less than 15 or 16, we become able to perceive them separately. To be musical they must come fast enough to appear to coalesce. From 16 to 33,000 is about eleven octaves. The capacity to hear the higher tones varies in different persons. A sound audible to one may be silence to another. Some ears can not distinguish the squeak of a bat or the chirp of a cricket, while others are acutely sensitive to these shrill sounds. Indeed, the auditory nerve seems generally more alive to the short, quick vibrations than to the long, slow ones. The whirr of a locust is much more noticeable than the sighing of the wind through the trees.

To this, however, there are remarkable exceptions. The author knows a lady who is insensible to the higher tones of the voice, but acutely sensitive to the lower ones. Thus, on one occasion, being in a distant room, she did not notice the ringing of the bell announcing dinner, but heard the noise the bell made when returned to its place on the shelf.

The ability of the ear to detect and analyze sound is wonderful beyond comprehension. Sound-waves chase one another up and down through the air, superposed in entangled pulsations, yet a cylinder not larger than a quill conveys them to the ear, and each string of that wonderful harp selects its appropriate sound, and repeats the music to the soul. Though a thousand instruments be played at once, there is no confusion, but each is heard, and all blend in harmony.

Is not the ear the most perfect sense? A needle-woman will distinguish by the sound whether it is silk or cotton that is torn. Blind people recognize the age of persons by their voices. An architect, comparing the length of two lines separated from each other, if he estimate within $\frac{1}{30}$, we deem very accurate; but a musician would not be considered very precise who estimated within a quarter of a note ($128 \div 30 = 4$ nearly). In a large orchestra, the leader will distinguish each note of each instrument. We recognize an old-time friend by the sound of his voice, when the other senses utterly fail to recall him. The

musician carries in his ear the idea of the musical key and every tone in the scale, though he is constantly hearing a multitude of sounds.

Every one, not utterly destitute of a musical ear, is familiar with the fact that certain notes, when sounded together, produce a pleasant effect by their combination, while certain others produce an unpleasant effect. The combination of two or more notes, when agreeable, is called concord or consonance; when disagreeable, discord or dissonance.

The distinction is found to depend almost entirely on difference of pitch, that is, on relative frequency of vibration, so that the epithets consonant and dissonant can with propriety be applied to intervals.

Besides the difference as regards pleasant or unpleasant effect, it is to be remarked that consonant intervals can be identified by the ear with much greater accuracy than those which are dissonant.

CHAPTER VII.

ON LIGHT.

THE sunbeam comes to the earth as simply motion of ether-waves, yet it is the grand source of beauty and power. Its heat, light, and chemical energy work every-where the wonder of life and motion. In the growing plant, the burning coal, the flying bird, the glaring lightning, the blooming flower, the rushing engine, the roaring cataract, the pattering rain—we see only varied manifestations of this one protean energy which we receive from the sun.

PRODUCTION AND TRANSMISSION OF LIGHT.

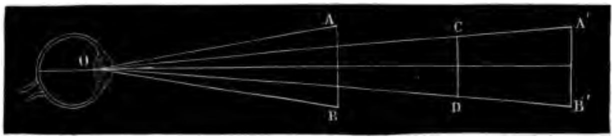
A LUMINOUS body is one that emits light. A medium is any substance through which light passes. A transparent body is one that obstructs light so little that we can see objects through it. A translucent body is one that lets some light pass, but not enough to render objects visible through it. An opaque body is one that does not transmit light. The terms transparent and opaque are relative. No substance is perfectly transparent, or entirely opaque. Glass obstructs some light. According to Miller, seven feet of the clearest water will arrest one half the light which falls upon it. While Young asserts that the beam of the setting sun, passing through 200 miles of air, loses $\frac{199}{200}$ of its force. On the other hand, gold, beaten into leaf, becomes translucent, transmitting green light; and scraped horn is semi-transparent. A ray of light is a single line of light. A pencil or beam of light is a collection of rays, which may be parallel, diverging, or converging; it may be traced in a dark room into which a sunbeam is admitted by the floating particles of dust which reflect the light to the eye.

The visual angle is the angle formed at the eye by rays *coming from the extremities* of an object. The angle AOB is *the angle of vision subtended* by the object AB. The size of

this angle varies with the distance of the body. AB and $A'B'$ are of the same length, and yet the angle $A'OB'$ is smaller than AOB, and hence $A'B'$ will seem shorter than AB. The distance and the apparent size of objects are intimately connected, since by experience we

The Visual Angle.

FIG. 159.



Variation of Visual Angle with Distance.

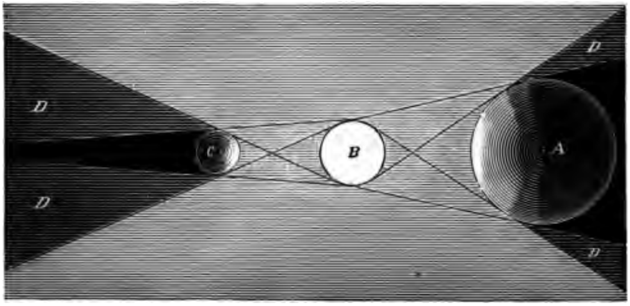
have learned to associate them. Knowing the distance of an object, we immediately estimate its size from the visual angle. We can vary the apparent size of any body at which we are looking, by increasing or diminishing this angle—a principle that will be found of great importance in the formation of images by mirrors and lenses.

Shadows.

When light falls upon an opaque body, inasmuch as the rays are transmitted in straight lines, the space behind the body from which the light is excluded is called a shadow.

If the source of light be a point, the shadow will be sharply

FIG. 160.

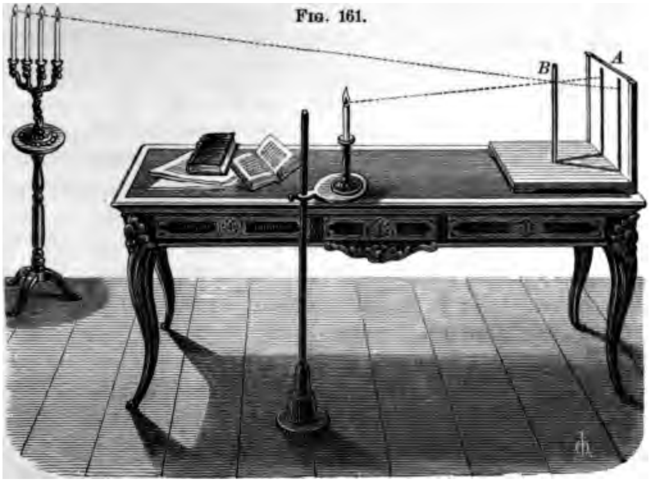


defined; if it be larger than a point, the perfect shadow will *be surrounded* by a fainter one called the penumbra. The *darker shadow* is called the umbra.

In Fig. 160 we have these two shadows represented, both the luminous and opaque bodies being spheres. If the luminous surface, *B*, be larger than the opaque body, the umbra will terminate in a point, as in the case of the shadow of *C*. It will be fringed by a penumbra, *DD*.

But, if the opaque body be larger than the luminous, the umbra will be divergent, as seen in the shadow of *A*. This is also fringed by a penumbra, *DD*.

Fig. 161.



If the luminous sphere be of the same size as the opaque, the umbra will be a cylinder, with a penumbra for a border.

The penumbra is less dark than the umbra, because only a part of the rays from the luminous body are cut off from the space it occupies.

Intensity of Light.—Photometry.

The intensity of light is the amount of disturbance it imparts to the ether. It is proportional to the square of the amplitude of the vibration of the ether particles; that is, as the amplitude increases the intensity increases, as it decreases the *intensity also decreases*. The intensity also varies inversely *as the square of the* distance from its source.

Hence we see that light follows the same law with regard to its intensity that is observed for gravity and sound. The law of variation of intensity can be verified, experimentally, by means of an instrument called a photometer.

A photometer is an instrument for comparing the intensities of different lights.

Several different instruments have been devised for this purpose, one of the simplest being that shown in Fig. 161.

If two equal lights are placed at equal distances from B, it is found that the shadows which B casts upon A are of the same tint. If one light be placed at any distance, and four equal lights be placed at twice the distance, the shadows will be of the same tint; this is the case shown in the figure. It will require nine equal lights at three times the distance, sixteen at four times the distance, and so on, to produce the same effect. This experiment confirms the law of variation of intensity according to the inverse square of the distance.

To use the photometer to compare the intensities of any two lights, let them be placed, by trial, at such distances from B that the shadows cast on A are of exactly the same tint; then will their intensities be to each other as the squares of their distances from the rod, B.

Laws of Light.

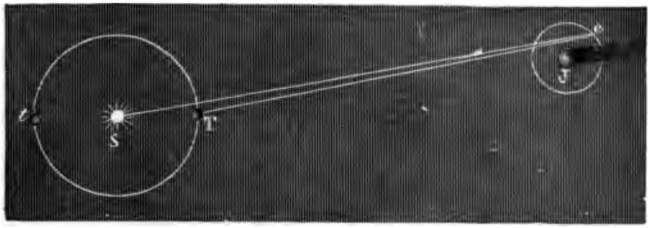
Light passes off from a luminous body equally in every direction. It travels through a uniform medium in straight lines. Its intensity decreases as the square of the distance increases. The ancients knew that light is propagated in straight lines. The law of intensity of light was established by Kepler, and the first researches on the comparison of intensity from different sources were made by Maurolycus, Huygens, and Francis Marie.

The Velocity of Light.

The velocity of light has been determined in various ways. The following was the first method, used by Roemer in 1676. The planet Jupiter has four moons. As these revolve around the planet, they are eclipsed at regular intervals. In Fig. 162, let J represent Jupiter, e one of the moons, S the sun, and T and t different positions of the earth in its orbit around the sun. *When the earth* is at T, the eclipse occurs 16 min. and 36 sec. *urlier than at* t. That interval of time is required for the

light to travel across the earth's orbit, giving a velocity of about 186,000 miles per second. This rate is so great that for all distances on the earth it is instantaneous. A sunbeam

FIG. 162.



The Sun, Earth, and Jupiter.

would girt the globe quicker than we can wink, if its path could be appropriately curved.

Undulatory Theory of Light.

There is supposed to be a fluid, termed ether, constituting a kind of universal atmosphere, diffused through space. It is so subtle that it glides among the molecules of bodies as the air does among the branches and the foliage of trees. It fills the pores of all substances, eludes all chemical tests, passes in through the receiver, and remains even in the vacuum of an air-pump. A luminous body sets in motion waves of ether, which go off in every direction. They move at the rate of 186,000 miles per second, and, breaking upon the eye, give the impression of sight. In the wave-motion of light, the vibrations are transverse (crosswise). Thus, if we suppose a star directly overhead, and a ray of light coming down to us, we should conceive that some of the particles which compose the waves are vibrating E. and W., others N. and S., and others toward all other possible points of the compass in succession.

In 1665, Grimaldi discovered the existence of fringes of light and shade when a beam is received through a narrow slit. Huygens soon afterward advanced the undulatory theory, which was originated independently about the same time by Hooke. This involved them in vigorous disputes with Newton, without the *definite establishment* of their theory. In 1802, Thomas *Young revived the* undulatory theory, accounting by it for all

the phenomena of interference then known. In 1817, Fresnel extended the researches of Young, and Newton's corpuscular theory began to fall into discredit.

REFLECTION OF LIGHT.

Light falling on a surface is divided into two portions. One enters the body; the other is reflected according to the familiar law of Motion and of Sound: The angle of incidence is equal to that of reflection.

The amount of light reflected varies with the angle at which light falls. Thus, if we look at the images of objects in still water, we notice that those near us are not so distinct as those on the opposite bank. The rays from the latter striking the water more obliquely, are more perfectly reflected to the eye.—Fill any dark-colored pail with water tinted with bluing or red ink. The color will be quite invisible to a spectator at a little distance. Now insert in the water a plate. This will reflect the transmitted light and reveal the hue of the water.

Action of Rough and Polished Surfaces.

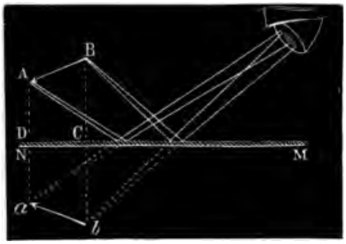
When the surface is rough, the numerous little elevations scatter the reflected rays in every direction, forming diffused light. Such a body can be seen from any point. When the surface is polished, the rays are uniformly reflected in particular directions, and may bring to us the images of other objects. We thus see non-luminous objects by irregularly-reflected (diffused) light, and images of objects by regularly-reflected light. The most perfectly polished substance, however, diffuses some light—enough to enable us to trace its surface; were it not so, we should not be aware of its existence. The deception of a large plate-glass mirror is often nearly complete; but dust or vapor, increasing the irregular reflection, will bring its surface to view.

Mirrors.

All highly-reflecting surfaces are mirrors. These are of three kinds—*plane*, *concave*, and *convex*. The first has a flat surface; the second, one like the inner surface of a hollow globe; the third, like art of its outer surface. The general principle of mirrors is at *the image* is seen in the direction of the reflected ray as it *ters the eye.*

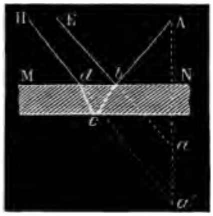
Rays of light retain their relative direction after reflection from a plane surface. While standing before a plane mirror, one sees his image erect and of the same size as himself. It is, however, reversed right and left. A book held in various positions before a looking-glass illustrates the action of plane mirrors. A beam of light admitted into a dark room and reflected from a mirror will show that the angles of incidence and reflection are in the same plane. Many of the grotesque effects of concave and convex mirrors may be seen on the inner and outer surfaces of a bright spoon, call-bell, or metal cup.

FIG. 163.



The image appears to be as far behind the mirror as the object is in front. Let AB be an arrow held in front of the mirror MN. Rays of light from the point A striking upon the mirror at C, are reflected, and enter the eye as if they came from a. Rays from B seem to come from b. Since the image is seen in the direction of the reflected rays, it appears at ab, a point which can easily be proved to be as far behind MN as the arrow is in front of it. Such an image is called a virtual one, as it has no real existence apart from the observer's eye.

FIG. 164.



Metallic mirrors form only a single image. If, however, we look obliquely at the image of a candle in a looking-glass, we shall see several images, — the first feeble, the next bright, and the others diminishing in intensity. The ray from A is in part reflected to the eye from the glass at b, and gives rise to the image a; the remainder passes on and is reflected from the metallic surface at c, and coming to the eye forms a second image a'. The ray cd, when leaving the glass at d, loses a part, which is reflected back to form a third image. This ray in turn is divided to form a fourth, and so on.

If two mirrors are arranged as in Fig. 165, three images of

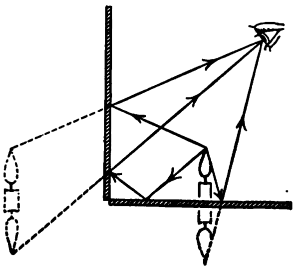
a candle may be seen. (Let the reader trace the formation of each by the diagram of Fig. 166.) To vary the experiment, hold the mirrors together like the covers of a book placed on

FIG. 165.

Multiple Reflection.

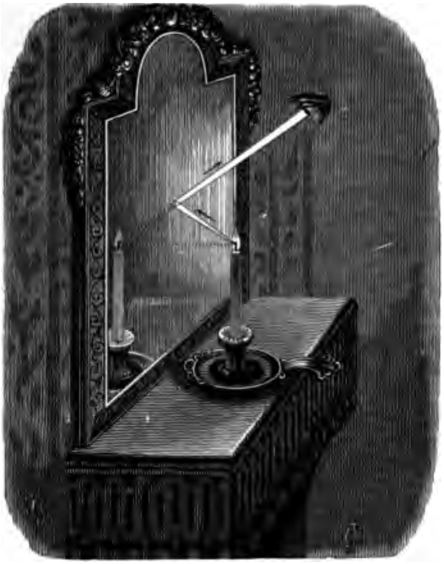
end, and put the candle between them on the table, opening and shutting the mirror-cover so as to vary the angle; or hold the mirrors parallel to each other with the light between them. When the mirrors are inclined at 90°, three images are formed; at 60°, five images; and at 45°, seven images. As the angle increases, the number diminishes. The images are upon the circumference of a circle whose center is on a line in which the reflecting surfaces would intersect if produced. Where the mirrors are parallel, the images are in a straight line. They become dimmer as they recede, light being lost at each reflection. — The Kaleidoscope contains three mirrors set at an angle of 60°. Small bits of colored glass at one end reflect to the eye at the other multiple images which change in varying patterns as the tube is revolved.

FIG. 166.



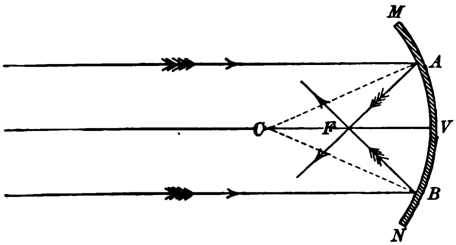
Images seen in water are symmetrical, but inverted. The reason of this can be understood by holding an object in front of a horizontal looking-glass and noticing the angle at which the rays must strike the surface in order to be reflected to the eye. When the moon is high in the heavens, we see the image in the water at only one spot, while the rest of the surface appears dark. The light falls upon all parts, but each ray is reflected from only one point at the proper angle to reach the eye. Each observer sees the image at a different place. When the surface of the water is ruffled, a tremulous line of light is reflected from the side of each tiny wave that is turned toward us. As every little billow rises, it flashes a gleam of light to our eyes, and then sinking, comes up beyond, to reflect another ray.

Fig. 167.



Reflection of Light.

Fig. 168.



Parallel Rays Reflected to the Focus.

A concave mirror tends to collect the rays of light to a focus. In Fig. 168, C is the center of curvature, *i. e., the center of* the hollow sphere of which the mirror

is a part; V is the vertex, or middle of the mirror; F is the principal focus; it is half-way between C and V. Any ray which passes through C is an axis; it is called the principal axis if it pass also through V, otherwise it is a secondary axis. All axial rays are reflected back upon their own paths. All rays parallel to the principal axis cross at the principal focus after reflection, and conversely all rays which pass through the principal focus will be reflected parallel to the principal axis.

These statements are approximately true only for mirrors of slight curvature, where the angle MCN, or angular aperture, does not exceed 8° or 10°. When greater, the rays reflected near the edge of the mirror meet the principal axis VC, nearer the mirror than F. This is called the aberration of the mirror. The reflected rays will then cross at points in a curved surface called a caustic. A section of such a curve can be seen when the light of a candle is reflected from the inside of a cup partly full of milk. All of these phenomena can be proved mathematically to be necessary consequences of the one law, that the angles of incidence and reflection are equal.

The ancients discovered the laws of reflection, and one of the ancient fables is that Archimedes set fire to the Roman ships off Syracuse by means of concave mirrors. Euclid and Plato, however, thought that the ray of light proceeds from the eye to the object, an error that was long uncorrected. One thousand years did not bring much advancement in this department of knowledge.

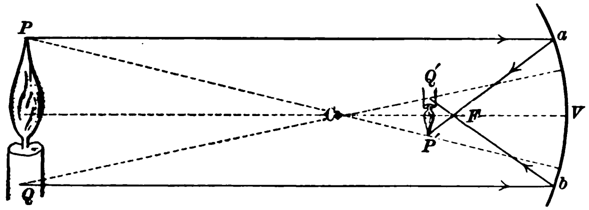
An image is real if the rays after reflection cross before reaching the eye; it will appear to be at the crossing point. Otherwise, the image is virtual.

In a dark room place a candle (PQ, Fig. 169) in front of a concave mirror at some distance beyond its center of curvature. A small inverted image of it will appear to be suspended in mid-air near its focus. It is easy to determine the position of this image. From P draw an axial ray through C; it will be reflected back on its own path, hence the image of P must be on this line. From P draw also a ray, Pa, parallel to the principal axis; after reflection it will pass through the focus, F, and cross the secondary axis at P', which is hence the position of the image of P. In like manner we may determine Q'. If

a piece of thin white paper or roughened glass be put at $P' Q'$, the light will seem to come from it since the rays cross here.

Bring the candle closer to the mirror. The image will grow larger and move from F toward C. When the candle reaches C, the image will fall upon it and just cover it. When it reaches $P'Q'$, the image will have receded to PQ, and in every

FIG. 169.

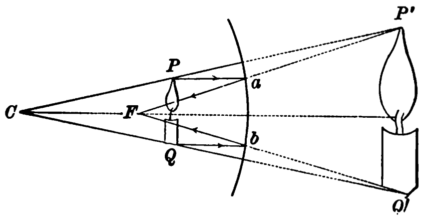


Inverted Real Image of a Candle.

case the ratio of the lengths of candle and image will be the same as the ratio of their distances from C. P and P' are called *conjugate points;* for they are so related together that an object placed at one of them will be imaged at the other.

If the candle be brought to F, the image will have grown still larger and more distant till it has vanished. When brought within F, the image suddenly appears as if it were behind the mirror, large and erect. Let the student trace the rays, as shown in Fig. 170, and satisfy himself that they can never cross after reflection. The image is hence virtual; it can not be caught on a screen; but its apparent length is as much greater than that of the candle as its apparent distance from C is greater. Moreover, it appears erect, and not inverted like the real image of the more distant candle.

FIG. 170.

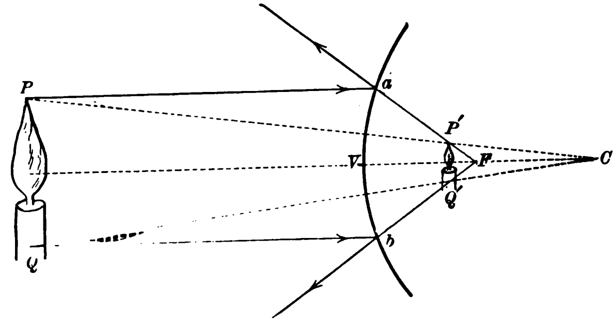


Virtual Image in a Concave Mirror.

Let the position of a candle be varied in front of a convex *mirror. It will be found* that the image is always virtual, erect,

and smaller than the candle. Parallel rays are made to diverge after reflection, as if they had come from a point within the sphere, half-way between its surface and center. The image of P is at the crossing point of the axial ray from P and the

Fig. 171.



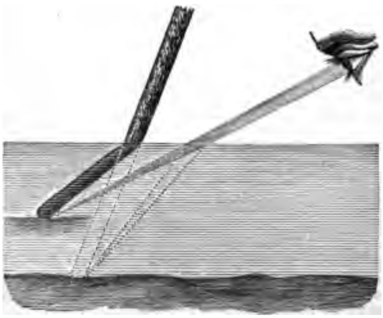
Virtual Image in a Convex Mirror.

backward prolongation of the ray from P which was parallel before reflection. The student can easily trace the rays and determine the position of the image

REFRACTION OF LIGHT.

When a ray of light passes obliquely from one medium to another of different density, it is refracted or bent out of its course.—A spoon in clear tea appears bent.—An oar dipping in still water seems to break at the point where it enters the water. The Arabian philosopher, Alhazen, who lived in the eleventh century, discovered the apparent displacement of a body seen in water.

Fig. 172.



Apparent breaking of a Stick in Water.

In Fig. 172 is shown a stick sunk till the end is at the bot-

tom of the water. Rays of light from this end are bent as they emerge from the liquid and reach the eye as if they had come from a point considerably higher. The entire bottom, therefore, seems lifted up. Hence, water is always deeper than it appears. Look obliquely into a pail of water, then place your finger on the outside where the bottom seems to be; you will be surprised to find the real bottom is several inches below.—Fill a glass dish with water, and, darkening the windows, let a sunbeam fall upon the surface. The ray will bend as it enters. Dust scattered through the air will make the beam distinct.

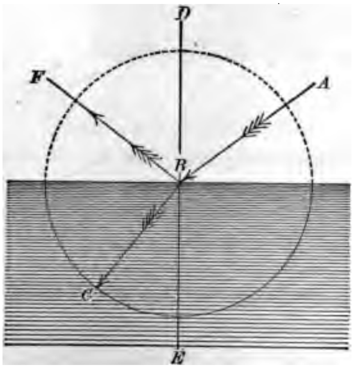
Put a cent in a bowl. Standing where you can not see the coin, let another person pour water into the vessel, when the coin will be lifted into view. To understand the apparent change of position, remember that the object is seen in the direction of the refracted ray as it enters the eye. Let L, Fig. 173, be a body beneath the water. A ray, LA, coming to the surface, is bent away from the vertical, LK, and strikes the eye as if it came from L'. The object will therefore apparently be elevated above its true place.

FIG. 173.

Laws of Refraction.

From any point, A, Fig. 174, let a beam of light, AB, pass through air and meet a denser transparent medium at B, such as water or glass. At this point let a line, DE, be drawn perpendicular to the surface. Then some of the light will be reflected at B, the angle of reflection, DBF, being equal to the angle of incidence, DBA. A little of it will be absorbed and changed into heat. The rest will be transmitted, but its direction changes to BC. This apparent breaking of the ray is called refrac

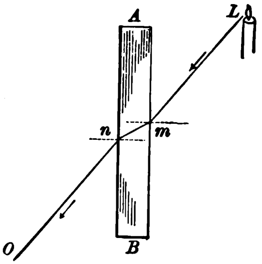
FIG. 174.



Reflection and Refraction.

tion, and the angle EBC, which is less than DBA, is the angle of refraction. If the source of light were at C, its direction on emerging at B would be BA. The angle of refraction now is DBA, and the angle of incidence is EBC. Hence, in passing into a denser medium, the ray is bent toward the perpendicular, and, in passing into a rarer medium, the ray is bent from the perpendicular.

FIG. 175.

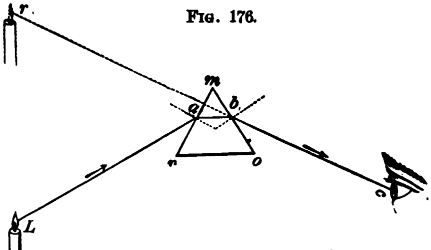


Passage of a Ray through Window glass.

Both the incident and the refracted ray lie in the same plane as the normal (perpendicular). The ratio between the sines of the angles of incidence and refraction is termed the index of refraction. It varies with the media. From air to water it is $\frac{4}{3}$ and from air to glass, $\frac{3}{2}$.

When a ray enters a window-glass, it is refracted toward the perpendicular, and, on leaving, is refracted equally from the perpendicular. The general direction of objects is therefore unchanged. A poor quality of glass produces distortion by its unequal density and uneven surface.

FIG. 176.



Passage of a Ray through a Prism.

A ray of light, on entering and on leaving a glass prism, is refracted. The inclination of the sides causes the ray to be bent twice in the same direction. The candle, L, will therefore appear to be in the direction of r.

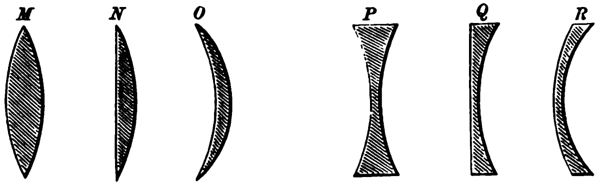
Lenses.

A lens is a transparent body, with at least one curved surface. There are two general classes of lenses, concave and convex. (See Fig. 177.)

The bi-convex lens has two convex surfaces. Its action on light is like that of a concave mirror. A ray, *striking* perpendicularly, is not refracted. The parallel rays,

M, *L*, etc., are refracted both on entering and on leaving the lens, and are converged at *F*, the principal focus. If a luminous point be placed at *F*, its rays will emerge parallel. The

FIG. 177.



Magnifying Lenses. Diminishing Lenses.

convex lens is sometimes termed a *burning-glass*, being used, like the concave mirror, for collecting the sun's rays. Lenses have been manufactured of sufficient power to melt a stone by sun-heat. Even glass globes of water, such as are used for gold-fishes or in the windows of drug stores, may fire adjacent objects.*

FIG. 178.

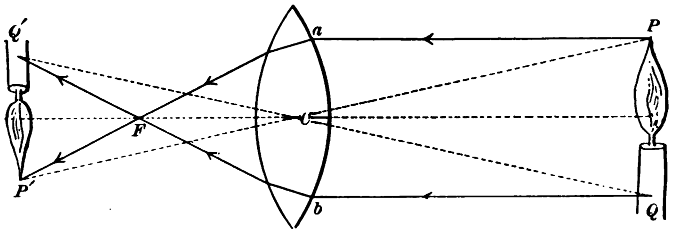
Bi-convex Lens.

There is a point, called the optical center of the lens, through which the passing ray does not change its general direction after emergence. These are called axial rays. The principal axis passes not only through the optical center (*C*, Fig. 179), but also through the principal focus, *F*. All rays parallel to it are so refracted as to pass through *F*. Let a candle, *PQ*, be placed in front of a bi-convex lens, at a distance of ten or twelve feet. An axial ray, *PC*, continues its path unchanged. A parallel ray, *Pa*, will after refraction pass through *F*. Where

* Forms of lenses are,—*M*, double-convex; *N*, plano-convex; O, meniscus (*crescent*); *P*, double-concave; *Q*, plano-concave; R, concavo-convex. The first three are styled magnifiers, and the second, diminishers.

this cuts the axial ray at P', the image of P is found. In like manner Q' is found as the point conjugate to Q. The image, $P'Q'$, is real, and may be caught on a screen. It is inverted, and as much smaller than the object as its distance from the optical center is less. An ordinary magnifying hand-glass, such as is often used in looking at photographs, or even a spectacle-lens used by an aged person in reading, will be sufficient for these experiments.

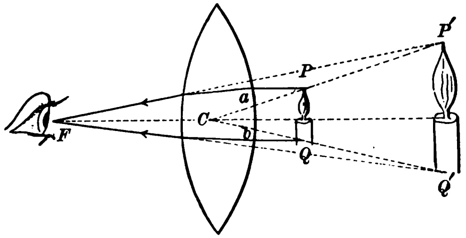
FIG. 179.



Formation of an Image with a Bi-convex Lens.

As the candle is made to approach the lens on one side, the image recedes on the other. When brought nearly to F, the image on the other side grows very large and distant. When it arrives within the focal distance, FC, the image suddenly appears on the same side with the object, erect, and as much larger as its apparent distance from C is greater. This image is virtual. The student can determine this by tracing the rays in Fig. 180.

FIG. 180.



Virtual Image with Convex Lens.

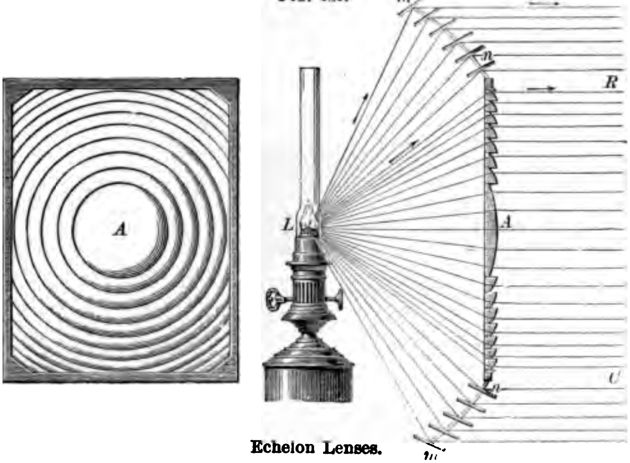
Light-house Lenses.

Parabolic mirrors were formerly used in light-houses. These, however, soon became tarnished *y the influence* of sea-fogs, and have been supplanted by *lano-convex* lenses. In the case of reflectors, the lamp itself

cuts off considerable light. In the principal foci of the lenses powerful lamps are placed, so that the emergent rays form a parallel beam, which enables the light to be seen at a distance of many miles.

The difficulty of constructing large plano-convex lenses, together with their great absorption of light, led finally to the

Fig. 181.



Echelon Lenses.

adoption of a particular system of lenses, known as echelon lenses.

Fig. 181 shows a front view, and a section of profile of an echelon lens.

A lens of this kind consists of a plano-convex lens, *A*, about a foot in diameter, around which are disposed several annular lenses, which are also plano-convex, and whose curvature is so calculated that each one shall have the same principal focus as the central lens, *A*.

A lamp, *L*, being placed at the principal focus of this refracting system, as shown in Fig. 181, the light emanating from it is refracted into an immense beam, *RC*, of parallel rays.

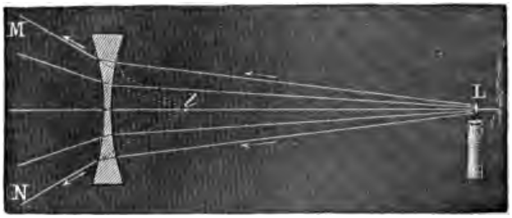
Besides this refracting system, several ranges of reflectors,

mn, are so disposed as to reflect such light as would otherwise be lost, to increase the beam of light formed by refraction.

In order that all the points of the horizon may be illuminated, a system of these lenses is made to revolve on a vertical axis by clock-work.

In consequence of this rotation, an observer at any point will see flashes of light and intervals of darkness following each other alternately. By suitably regulating the number of revolutions in any given time, different light-houses may be distinguished from each other. These alternations also serve to distinguish light-houses from a star or accidental fire.

FIG. 182.



Bi concave Lens.

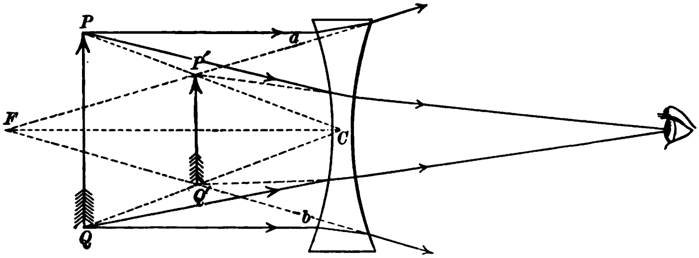
The electric light is used at the present time to some extent in light-houses, the electricity being generated by magneto-electric machines operated by steam.

The bi-concave lens has two concave surfaces. Its action on light is like that of a convex mirror. Thus, diverging rays from *L* (Fig. 182) are rendered more diverging, and, to an eye which receives the rays *MN*, the candle would seem to be at *l*, where the image is seen. Unscrew the eye-piece from an opera-glass; it serves well for experiments with concave lenses. Unscrew the glass at the other end; it serves for those with convex lenses.

The image formed by a concave lens, like that of a convex mirror, is virtual, erect, and diminished in size (Fig. 183). Let the student determine this by tracing the rays in Fig. 183, in which the arrow *PQ* is the object and *P'Q'* the image. Remember that parallel rays, *Pa* and *Qb*, become divergent after refraction, as if they had come from a focus, F, on the same

side of the lens. The images of P and Q must hence be found on the *backward* prolongations of these emergent rays. Axial rays are drawn from P and Q to C.

FIG. 183.



Formation of an Image with a Concave Lens.

Spherical Aberration of Lenses.

Parallel rays falling on a lens whose surface is like that of a sphere are not all refracted to a single focus. Those which pass through marginal parts of the lens are collected to a focus nearer than that to which the central rays are collected. With a single lens, therefore, it is not easy to secure perfect distinctness of image.

FIG. 184.

Total Internal Reflection.

Total Reflection.

In passing from a dense into a rare medium, the angle of refraction is greater than the angle of incidence. It can not exceed 90°, for then the ray would cease to emerge. The angle of incidence for which the emergent ray would make an angle of 90° with the perpendicular is called the critical angle. The light is then totally reflected in the dense medium as if its surface were the most perfect of mirrors. When we look obliquely into a pond, we can not see the bottom, because the rays of light from below are reflected downward

at the surface of the water. Hold a glass of water above the level of the eye, and the upper part will gleam like burnished silver. Place a bright spoon in the glass, and notice its image reflected from the surface of the water. Turn the spoon about in the glass, and, changing the angle of observation, notice the effect. The real handle may apparently be attached to the image in the water. The spoon will soon be covered with bubbles of air shining, like pearls, from total reflection. This shows also the presence of air in water and the adhesion of gases to solids. Thus the internal surface of a transparent body becomes a mirror.

Mirage.

Over the heated deserts of Arabia and Africa the traveler sometimes sees a shimmering expanse, as if a quiet lake were in the distance, in which the scattered trees are mirrored upside down. The layer of air close to the uniformly heated sand is less dense

Fig. 185.

Mirage.

than the cooler air above. A ray coming obliquely downward from a tree-top may be so bent from its first direction by passing through these different media as to be sent obliquely upward to the eye. The low warm layer of air acts like a totally *reflecting* mirror, and inverted images are dimly seen amid the *bright light* along the horizon. In Fig. 185, rays of light from

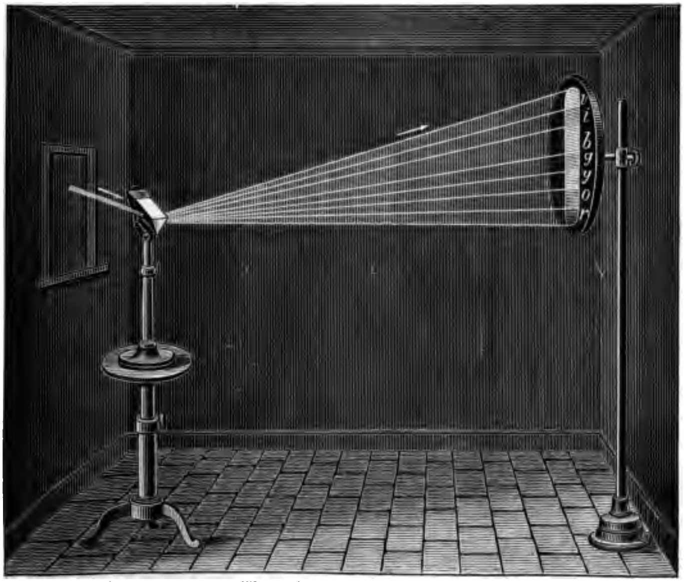
a clump of trees are refracted more and more until finally they are bent upward from a layer at *a*, and enter the eye of the Arab as if they came from the surface of a quiet lake.

COMPOSITION OF LIGHT.

The Prismatic Spectrum.

When a sunbeam is received through a narrow slit and transmitted through a prism, properly placed, the ray is not only bent from its course, but is also spread out into a band of rainbow colors—the solar spectrum. This includes a multitude of tints grading

Fig. 186.



The Prismatic Spectrum.

imperceptibly from one to another. The most prominent are violet, indigo, blue, green, yellow, orange, red. Notice that the initial letters spell the mnemonic word, *Vib-gy-or*.

If we receive the spectrum on a concave mirror, or pass it *through a convex* lens appropriately adjusted in position, these

colors may be recombined so as to form a white band. We therefore conclude that white light is made up of these many tints. Because each has its own separate index of refraction when passing through the same prism, they are refracted unequally. The deviation of the violet is the greatest, and that of the red is the least, for the visible rays of the spectrum.

Solar Energy.

What we receive from the sun is called solar energy. It reaches us in tiny waves, the longest of which are so minute that 8,000 of them in succession would be required to cover an inch. The shortest that have been measured are about a tenth as long, or $\frac{1}{80\,000}$ of an inch. The longer ones are manifested largely as heat; some of the intermediate ones as light, and the shortest as chemical energy, giving vigor to the growing plant and disturbing the arrangement of molecules on the photographer's sensitive plate. All these waves come mixed together in the sunbeam. The prism changes their direction, but not in proportion to wave-lengths. It crowds together some and separates others unequally. The prismatic spectrum includes the invisible heat and chemical rays, as well as the visible light waves.

The Normal Spectrum.

By using a diffraction grating instead of a prism, a spectrum is obtained in which the deviation is proportional to wave-length. In such a spectrum it is found that rays of all colors may be manifested as heat, light, or chemical energy, according to the means used to reveal the presence of the solar energy. To the human eye some of them are imperceptible, yet these have been photographed and the dark parts explored by the aid of instruments far more sensitive than our nerves. They all convey heat; only those whose wave-length is between $\frac{1}{60\,000}$ and $\frac{1}{40\,000}$ of an inch affect the eye with the sensation of light. Of these the shortest are manifested as violet, the longest as red. Each of the intermediate tints has its own wave-length.

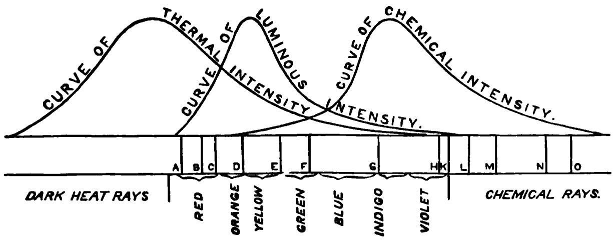
Interruptions in the Spectrum.

When the spectrum of the sun, whether prismatic or normal, is carefully examined, it is found that there are numerous breaks in both the visible and invisible parts. Numerous black lines, parallel *to the slit that* transmits the light, may be detected in the

visible part. These are seen to best advantage in a spectrum formed by passing a beam of sunlight through a narrow slit, and then decomposing it by a prism whose edges are parallel to the slit. The prism should be of flint glass and free from flaws. If the slit be wide the colors will overlap one another, but in a pure spectrum this must not be. A pure spectrum is obtained by making the slit very narrow.

The dark lines of the solar spectrum were noticed by Wollaston as early as 1802, but they were first studied and mapped by Fraunhofer in 1814; from that fact they have been called Fraunhofer's lines. The more prominent of these have been named. Thus, the *A*, *B*, and *C* lines are in the red; the *D* line

FIG. 187.



in the yellow; the *E* line in the green; the *F* line in the blue; the *G* and *H* lines in the violet. The interruptions in the invisible portion are far broader, becoming bands rather than narrow lines.

Fraunhofer's chart contains between five and six hundred lines irregularly distributed. He counted nine lines between *B* and *C*; thirty between *C* and *D*, eighty-four between *D* and *E*, seventy-five between *E* and *F*, one hundred and eighty-five between *F* and *G*, and one hundred and ninety between *G* and *H*. Recent observations have increased the number of dark lines till they are now counted by thousands.

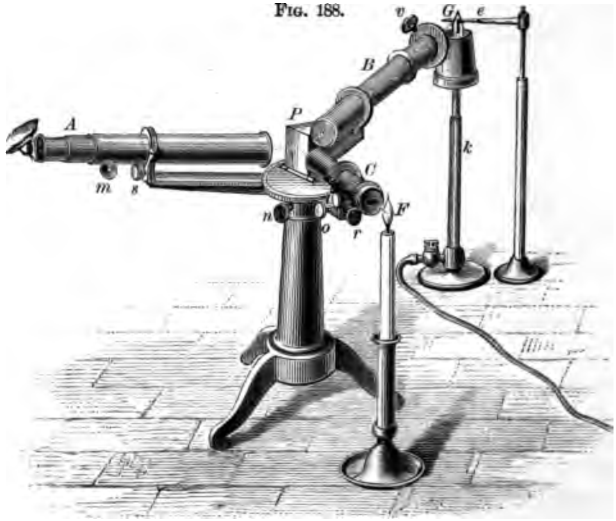
Fraunhofer found the spectra of the fixed stars to be crossed by dark lines, but the lines are differently arranged in the different stars, and in none are they arranged as in the solar spectrum. The spectra of the moon and planets whose light is reflected from the sun give the same lines as those of

the sun. Recently the range of observation has been vastly increased, and on the results of these examinations a new branch of science has been founded, called spectrum analysis.

The Spectroscope.

Any instrument for examining the spectrum is a spectroscope. The simplest is the single prism or diffraction grating. But in connection with either of these it is better to use telescopes. From the source of light, *G*, Fig. 188, the rays pass through an adjustable slit and are made parallel by the lens in the tube, *B*, before

Fig. 188.



The Spectroscope.

passing through the prism, *P*. The spectrum is seen through the telescope, *A*. The tube, *C*, has at one end a scale on glass through which passes the light from a candle or coal-gas jet at *F*. This is reflected from the surface of the prism into the telescope *A*, where an image of the scale is seen alongside of the spectrum. Each part of the spectrum can thus be distinguished by its own scale number. Instead of a single prism, often a train of prisms is used, thus widening the spectrum and diminishing its brightness. The spectroscope affords an unrivaled mode of analysis. No chemical test is so delicate.

Strike together two books near the light at the slit of the spectroscope, and the dust blown into the flame will contain enough sodium (the basis of common salt) to cause the yellow *D* lines —its test—to flash out distinctly. A very effective spectroscope may be contrived thus: Cut a slit not over $\frac{1}{20}$ inch wide and two inches long in a piece of tin-foil, and gum it on a pane of glass. Hold this before a flame and look at it through a prism.

Three Kinds of Spectra.

If in the spectroscope we examine the light of a glowing thin gas or vapor, its spectrum is seen to consist of one or more bright lines only. Thus burning sodium gives a pair of brilliant yellow lines close together; zinc vapor, a number of lines among which the blue are very prominent; and strontium, a number among which the red are conspicuous. Each element, if made gaseous, can be thus recognized by its spectrum.

If the light from a glowing solid be examined, its spectrum is found to be continuous, giving all the colors without interruption. White-hot lime, or the particles of carbon in a common candle-flame, furnish a continuous spectrum.

The bright lines given by a glowing gas may be made to broaden into bands; and these finally to become joined into a nearly continuous spectrum by subjecting the gas to very great pressure, and thus making it very dense. There is no sharp distinction between line spectra and continuous spectra.

The interrupted spectrum is that given by the sun and stars. It may be produced to a limited extent by interposing a glowing vapor, like that of sodium, between the spectroscope and a white-hot solid, like lime. It is believed that the body of the sun and of each of the stars is made up of very dense glowing matter, which is surrounded by less hot vapors. These absorb some of the light from within, and thus produce the interruptions observed in the spectra of the sun and stars. Moreover, it has been proved that each gas or vapor absorbs the same waves as those given out by itself in glowing. By comparing the bright lines of a known gas or vapor with the dark lines in the sun or star spectrum, it becomes possible to determine whether this vapor exists in the atmosphere of the sun or star.

Color. If a piece of pure red paper is put against the successive parts of the spectrum on a screen, it will look red only when in the red part, but dark gray or black in the other parts. It reflects red light and absorbs the other tints. Color is analogous to pitch, violet corresponding to the high and red to the low sounds in music. Intensity of color, as of sound, depends on the amplitude of the vibrations. When a body absorbs all the colors of the spectrum except blue, but reflects that to the eye, we call it a blue body; when it absorbs all but green, we call it a green body.

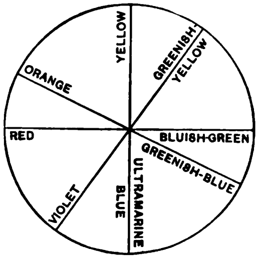
Some eyes are blind to certain colors, as some ears are deaf to certain sounds. "Color-blindness" generally exists as to red. A person who is color-blind, can not by the color distinguish ripe cherries from green ones. Doubtless railway accidents have occurred through this inability to apprehend signals. Dr. Mitchell mentions a naval officer who chose a blue coat and red waistcoat, believing them of the same color; a tailor who mended a black silk waistcoat with a piece of crimson; and another who put a red collar on a blue coat. Dalton could see in the solar spectrum only two colors, blue and yellow, and having once dropped a piece of red sealing-wax in the grass, he could not distinguish it.

Red glass has the power of absorbing all except the red rays, which it transmits. When a substance reflects all the colors to the eye, it seems to us white. If it absorbs all the colors, it is black. Thus color is not an inherent property of objects. In darkness all things are colorless. Moisten a swab with alcohol saturated with common salt. On igniting this in a dark room, every object will take on a curious ghastly yellow hue from the burning sodium. The gay colors of flowers will instantly be quenched.

Complementary Colors. Two colors, which by their mixture produce white light, are termed complementary to each other. Thus, if we sift the red rays out of a beam of light and bring the remainder to a focus, a bluish-green image will be formed. Certain substances are able to split a *ray of light* into two colors, and are said to be dichroic. Gold-*leaf reflects* the yellow, transmits the green, and absorbs the rest.

In Fig. 189 the colors opposite each other are complementary. Place a red and a blue ribbon side by side. The former will take on a yellowish and the latter a greenish tint. Lay a piece of tissue paper upon black letters printed on brightly colored paper. The dark letters will appear of a color complementary to that of the background.

Fig. 189.



Complementary Colors.

A color is heightened when placed near its complement. A red apple is the brighter for the contrast of the green leaf. Observe a white cloud through a bit of red glass with one eye and through green glass with the other eye. After some moments, transfer both eyes to the red glass, opening and closing them alternately. The strengthening of the red color in the eye, fatigued by its complementary green, is very striking. In examining ribbons of the same color, the eye becomes wearied and unable to detect the shade, because of the mingling of the complementary hue.

The Rainbow.

The rainbow is formed by the refraction and reflection of the sunbeam in drops of falling water. The white light is thus decomposed into its simple colors. The inner arch of the rainbow is termed the primary bow; the outer or fainter arch, the secondary.

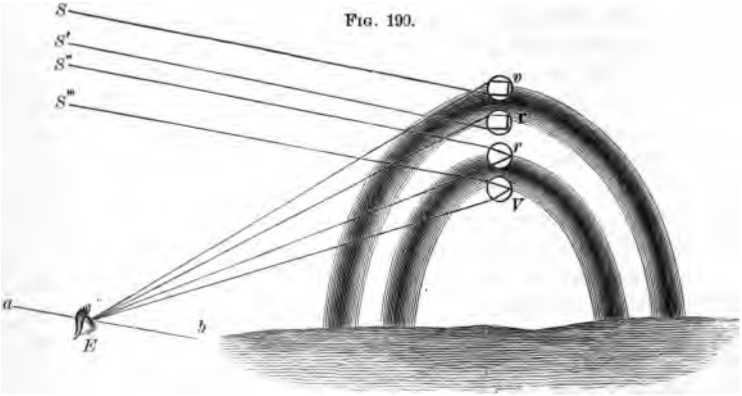
A ray of light, *S''*, enters, and is bent downward at the top of a falling drop, passes to the opposite side, is there reflected, then passing out of the lower side, is bent upward. By the refraction, the ray of white light is decomposed, so that when it emerges it is spread out fan-like, as in the solar spectrum. Suppose that the eye of a spectator is in a proper position to receive the red ray, he can not receive any other color from the same drop, because the red is bent upward the least, and all the others will pass directly over his head. He sees the violet in a drop below. Intermediate drops furnish the other colors of the spectrum.

A ray of light, *S*, strikes the bottom of a drop, *v*, is refracted upward, passes to the opposite side, where it is twice reflected, and thence passes out at the upper side of the drop.

The violet ray being most refracted, is bent down to the eye of the spectator. Another drop, *r*, refracting another ray of light, is in the right position to send the red ray to the eye.

When the red ray of the primary bow leaves the drop, it forms an angle with the sun's ray, *S''r*, of about 42°, and the violet forms with it one of 40°. These angles are constant. Let *ab* be a straight line drawn from the sun through the observer's eye. If produced, it would pass through the center of the circle of which the rainbow is an arc. This line is termed the visual axis. It is parallel to the rays of the sun; and when

FIG. 190.



The Rainbow.

it is also parallel to the horizon, the rainbow is a semicircle. Suppose the line *EV* in the primary bow to be revolved around *Eb*, keeping the angle *bEV* unchanged; the point *V* would describe an arc of a circle on the sky, and every drop over which it passed would be at the proper angle to send a violet ray to the eye at *E*. Imagine the same with the drop *r*. We can thus see the bow must be circular; when the sun is high in the heavens, the whole bow sinks below the horizon; the lower the sun, the larger is the visible circumference; and on lofty mountains a perfect circle may sometimes be seen. Halos, coronas, sun-dogs, circles about the moon, and the tinting at *sunrise and sunset*, are produced by the refraction and reflection *of the sun's rays* by the clouds. The phenomenon known as the

"sun's drawing water," consists of the long shadows of broken clouds. Twilight and kindred topics are treated in Astronomy.

Chromatic Aberration of Lenses.

Since in passing through any medium, such as a lens, the violet rays are bent farther away from their first direction than the red rays, they will be brought to a focus nearer than that of the red rays. An image on a screen produced with a single lens is therefore fringed with a reddish or a bluish fringe according to the position of the screen. By combining two lenses properly, one made of crown glass and the other of flint glass, it is possible to correct much of this coloring, which is called chromatic aberration, and at the same time much of the spherical aberration. The crown-glass lens must be bi-convex and the flint-glass lens plano-concave or meniscus. Flint glass gives a spectrum nearly twice as wide as crown glass. The two lenses oppose each other in their action on light. They may be so adjusted that each tends almost completely to reverse the spectrum that the other would produce, and yet the excess of deviation produced by the crown glass may still be enough to bring the rays of this nearly white light to a focus.

Newton's Rings.

Let the convex side of a plano-convex lens be pressed down upon a plane of glass. The two surfaces will apparently touch at the center. If different circles be described around this point, at all parts of each circle the surfaces will be the same distance apart, and the larger the circle the greater the distance. Now let a beam of red light fall upon the flat surface. A black spot is seen at the center; around this a circle of red light, then a dark ring, then another circle of red light, and so alternating to the circumference. The distances between the surfaces of the glass, where the successive dark rings appear, are proportional to the numbers 0, 2, 4...., and the bright circles to 1, 3, 5..... This fact suggests the cause. There are two sets of waves, one reflected from the upper surface of the plane glass, and the other from the lower surface of the convex glass. These alternately *interfere*, producing darkness, and *combine, making an intenser color.*

Fig. 191.

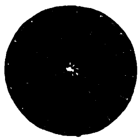
Production of Newton's Rings.

The play of colors in mother-of-pearl is due to the interference of light in its thin overlapping plates. In a similar manner the plumage of certain birds reflects changeable hues. A metallic surface ruled with fine parallel lines not more than $\frac{1}{2000}$ of an inch apart, gleams with brilliant colors. — Thin cracks in plates of glass or quartz, mica when two layers are slightly separated, even the scum floating in stagnant water, breaks up the white light of the sunbeam and reflects the varying tints of the rainbow. The rich coloring of a soap-bubble is caused by the interference of the rays reflected from the upper and lower surfaces of the bubble. Diffraction is interference produced by a beam of light passing along the edge of an opaque body or through a small opening, or reflected by a surface ruled with fine lines. Place the blades of two knives closely together and hold them up to the sky; waving lines of interference will shade the open space. Look at the sky through the meshes of a veil, or at a lamp-light through a bird-feather or a fine slit in a card, and delicate colors like those of the prism will appear.

To determine the length of a wave of red light, we have only to measure the distance between the two glasses at the first ring.

When beams of light of the various colors are used, corresponding circles are obtained, having different diameters; red light gives the largest, and violet the smallest. We hence conclude that red waves are the longest, and violet the shortest. The minuteness of these waves passes comprehension. About 40,000 red waves, or 60,000 violet ones, are comprised within a single inch. Knowing the velocity of light, we can calculate how many of these tiny waves reach our eyes each second. When we look at a violet object, 757 million million of ether-waves break on the retina every moment!

Fig. 192.



Polarization of Light.

If we could look at the end of a ray of light coming toward us, as we can at the end of a rod, we should see the molecules of ether *ibrating across* the direction of the ray in all possible planes, *s shown in Fig.* 193. There are certain conditions under

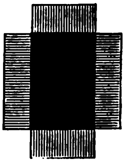
which reflected or refracted light may be made to vibrate in but a single plane. It is then called polarized light.

The crystal tourmaline has this power upon transmitted light. If two thin plates of this be cut parallel to the axis of the crystal and light be passed perpendicularly through them, when one is placed parallel to the other, as in Fig. 193, some of it will be absorbed, but what passes through vibrates only in a plane the same as that of the axis. This is proved by crossing them, as in Fig. 194; at once the light is quenched. What passed through the first plate had been polarized, and was stopped by the second plate when crossed. If the two plates be placed with axes oblique to each other, part of the polarized light is transmitted and part of it is quenched.

FIG. 193.

Tourmalines Parallel.

FIG. 194.



Tourmalines Crossed.

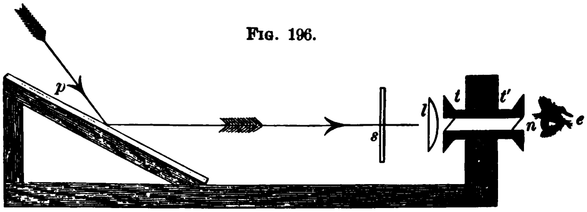
In tourmaline and many other crystals the ether is unequally elastic in two directions at right angles to each other. The light is hence divided into two parts which pass through with unequal velocities. If transmitted across the axis of the crystal, these parts are separated so that two beams become perceptible. Iceland spar shows this remarkably well. An object viewed through it appears double. If the crystal be placed over a dot and turned around, two dots will be seen; one appears a little nearer than the other, and revolves around it, or a word will appear double if viewed in like manner (Fig. 195). If now a plate of tourmaline be put between the eye and the rotating crystal of spar, the dots will alternately disappear. This shows that the two beams were polarized at right angles to each other. One of them is called the ordinary and the other the extraordinary ray. *Tourmaline is a doubly-refracting crystal in which the extraordinary ray is absorbed* unless the plate be exceedingly thin.

FIG. 195.

Double Refraction.

When light falls upon a surface of glass at such an angle that the reflected and refracted beams are at right angles to each other, each of these is polarized, just as in passing through a doubly-refracting crystal. This special polarizing angle of incidence for glass is about 56°. Many other substances polarize the light reflected at the proper angle from them. If a tourmaline is rotated before the eye while looking obliquely at the surface of a varnished table, or leather-seated chair, the reflected light will be found to be polarized. The elementary phenomena of polarization were discovered by Malus in 1808, and this subject was afterward studied with great thoroughness by Fresnel, Arago, Biot, and Brewster.

Fig. 196.



Polariscope.

The best polarizer is a crystal of Iceland spar specially arranged so as to transmit the extraordinary ray and quench the ordinary ray. It is called a Nicol's prism. Whatever is used for examining the light after it has been polarized is called an analyzer. The Nicol's prism makes the best analyzer also. An instrument that includes both polarizer and analyzer is called a polariscope. A glass plate fixed at the proper angle makes an excellent polarizer, and a small Nicol's prism, or piece of tourmaline, for analyzer is enough for many beautiful experiments. Exquisite displays of complementary colors, due to interference of polarized beams in transmission, may be seen by examining thin pieces of crystallized gypsum, mica, horn, stained glass, etc., between polarizer and analyzer. Polarized light affords a delicate means of examining the molecular structure of a body.

A simple polariscope is shown in Fig. 196. Upon a wooden frame a plate of glass, P, blackened on the under side, is fixed so that light falling on it at the polarizing angle shall be re-

FIG. 197

The Microscope.

flected through the tube *tt'*. This contains a small Nicol's prism, *n*, for analyzer, and a lens, *l*, through which an object, *s*, may be examined with polarized light. The student who makes one will find it a source of fascination and continued delight.

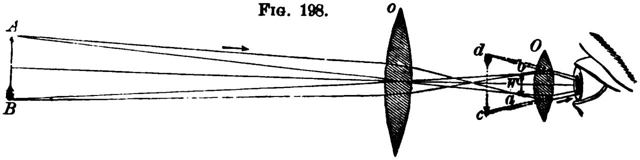
OPTICAL INSTRUMENTS.

Microscopes are of two kinds, simple and compound. The former *consists of one or* more convex lenses through which *the object is seen directly*; the latter contains a simple mag

nifier for viewing the image of an object produced by a second lens. Fig. 197 represents a compound microscope. At *M* is a mirror which reflects the rays of light through the object, *a*. The object-lens (objective), *o*, forms, in the tube above, a magnified, inverted image of the object. The eye-lens, *O* (ocular), magnifies this image. The magnifying power of the instrument is nearly equal to the product of that of the two lenses. If a microscope increases the apparent diameter of an object 100 times, it is said to have a power of 100 diameters, the surface being magnified $100^2 = 10{,}000$ times. The eye-piece may be only a single lens, and is really a simple microscope. The object-lens often consists of several lenses, and each one of a combination of convex crown glass and concave flint glass to prevent aberration.

Microscopes.

FIG. 198.



Formation of Image in the Telescope.

Telescopes.

Telescopes are of two kinds, reflecting and refracting. The former contains a large metallic mirror (speculum) which reflects the rays of light to a focus. The observer stands at the side and examines the image with an eye-piece. The largest reflecting telescope is that of Lord Rosse. Its speculum is 6 ft. in diameter, and gathers about 120,000 times as much light as would ordinarily enter the eye. About 1608, the telescope was invented by the Dutch. "In 1609, the government of Venice made a considerable present to Signor Galileo, of Florence, Professor of Mathematics at Padua, and increased his annual stipend by 100 crowns, because, with diligent study, he found out a rule and measure by which it is possible to see places thirty miles distant as if they were near, and, on the other hand, near objects to appear much larger than they are before our eyes." Jansen, Metius, and Lippersheim each claimed the honor, and the legend

is that the discovery grew out of some children at play, accidentally arranging two watch-glasses so as apparently to magnify an object. In fact, however, the action of the convex lens was already known, the compound microscope had been invented by Jansen twenty years previously, and the simple microscope was known to the ancient Chaldeans. In 1621, Snell discovered the law of refraction. By its aid, Descartes explained the rainbow. Half a century of waiting, and Newton published his investigations in the decomposition of light. He, however, believed in what is known as the "corpuscular theory." This holds that light consists of minute particles of matter radiated in straight lines from a luminous object, the ray being endued with alternate "fits" of easy reflection and easy transmission.

The refracting telescope contains an object-lens, *o*, which forms an inverted image, *ab*. This is viewed through the eye-piece, *O*, which produces a magnified image, *cd*, of the first image, *ab*. The image *cd* is as much larger than *ab* as the focal distance of the object-glass exceeds that of the eye-glass. The larger the object-lens the more light is collected with which to view the image. The magnifying power is due to the eye-piece. The use of the telescope depends upon its light-collecting and its magnifying power. Thus Herschel, illustrating the former point, says that once he told the time of night from a clock on a steeple invisible on account of the darkness. It is noticeable that while in the compound microscope the image is as much larger than the object as the image is farther than the object from the object-glass, in the telescope the image is as much smaller than the object as it is nearer than the object to the object-glass; while in both cases the image is examined with a magnifier. If a power of 1,000 be used in looking at the sun, we shall evidently see the sun as if it were only 93,000 miles away, or less than one half the distance of the moon. The same power used upon the moon would bring that body apparently to within 240 miles of us.

The National Observatory telescope at Washington has an object-glass twenty-six inches in diameter, and of excellent defining power. *The Lick telescope*, erected in 1887 upon Mt. *Hamilton, in California*, has an object-glass just one yard in

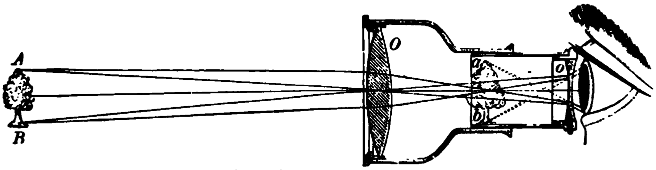
diameter. Its light-collecting power is estimated to be about 30,000 times that of the unaided eye. The apparent inversion

FIG. 199.

Cambridge Equatorial.

of the object is of no importance for astronomical purposes. In terrestrial observations additional lenses are used to invert the image.

FIG. 200.



Formation of Image in Opera-glass.

The opera-glass contains an object-glass, *O*, and an eye-*iece, o.* The latter is a double-concave lens; this increases

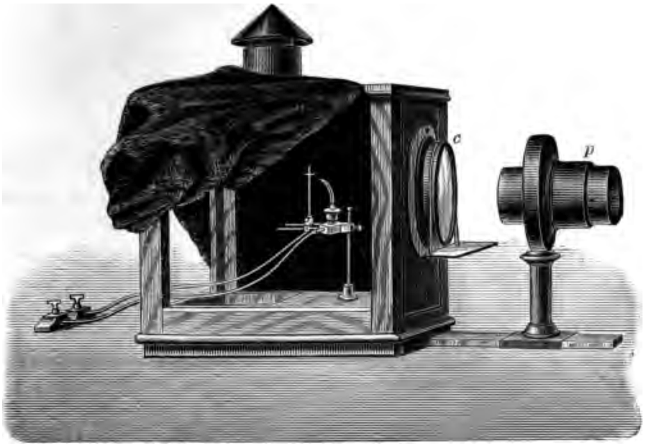
the visual angle by diverging the rays of light, which would otherwise come to a focus beyond the eyepiece. An erect and magnified image is seen at *ab*.

The Opera-glass.

The Projecting Lantern.

The projecting lantern consists of a system of lenses attached to a dark box, within which is a powerful source of illumination, such as the electric light or lime light. Sometimes an oil-lamp is used. From the white-hot source the light is converged by the condensing lens, *C*, Fig. 201, so as to send through the projecting lens, *P*, as much of it as possible. A picture on glass is placed

FIG. 201.



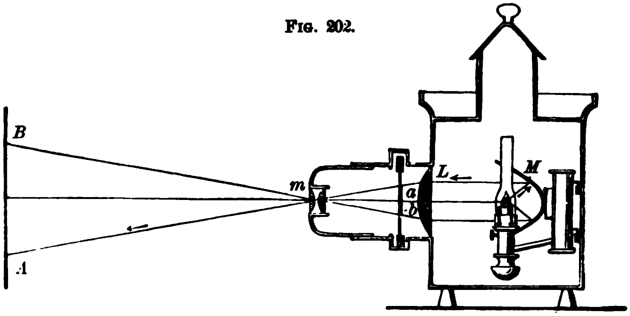
Projecting Lantern for the Lime Light.

in front of the condenser, and is thus strongly illuminated. An image of it, greatly enlarged, is formed by the projecting lens and focalized on a distant white screen in a dark room. Dissolving views are produced by using two lanterns together. While one view is on the screen, another is projected upon it. The light is then cut off from the first lantern so as to leave only the second view. *Fig.* 202 is an outline of one form of oil-lantern. *The reflector, M,* helps to illuminate the transparent *picture, ab, in front of the* condenser.

Camera Obscura.

The camera obscura (dark chamber) is, as its name indicates, a closed space, as, for example, a room shut off from the light, with the exception of the luminous rays that are allowed to enter through a small aperture, as shown in Fig. 203.

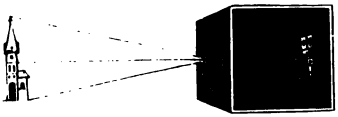
FIG. 202.



Projecting Lantern for the Oil Light.

The rays proceeding from external objects and entering through this aperture form on the side opposite the aperture an image of the object, inverted and diminished in size, but retaining the colors of the object. The inversion of the image is due to the crossing of the rays.

FIG 203.



Camera Obscura

If the aperture is a large one, the rays are scattered indiscriminately over the whole picture, and the image is not so distinct as when the aperture is small. The image will be distorted if the screen is not perpendicular to the direction of the rays.

The images formed by a camera obscura possess the remarkable peculiarity of being entirely independent of the shape of the opening, in the box, provided it be quite small. The shape of the images is the same, whether the opening be square, round, triangular, or oblong.

To show this, let us consider the case of a beam of solar light entering a dark room through a hole in a shutter. With respect to the sun, the hole in the shutter is but a point; hence

the group of rays which enter it form in reality a cone whose base is the sun. The prolongation of these rays into the room makes up another cone similar in shape to the first, and if this cone be intercepted by a screen perpendicular to the line joining the hole with the center of the sun, the image formed will be a circle. If the rays are intercepted by an oblique plane, the image is elliptical, but it never takes the form of the hole when that is small.

FIG. 204.

In accordance with this principle, we find the illuminated patches of earth formed by light passing between the leaves in a forest of a circular or elliptical shape. In an eclipse of the sun, when the visible portion of the sun is of crescent shape, the patches of light all assume the crescent form; that is, they are images of the visible part of the sun.

Portable Camera for Artists.

For taking views the camera obscura should be light and portable. The best form is that shown in Fig. 204. It consists of a sort of portable tent of black cloth, within which is a table for receiving the image, and at the top of which is a tube bearing a prismatic lens, that produces the combined effect of the mirror

and lens. The figure projected upon the table may be traced out with a pencil on a sheet of white paper.

FIG. 205.

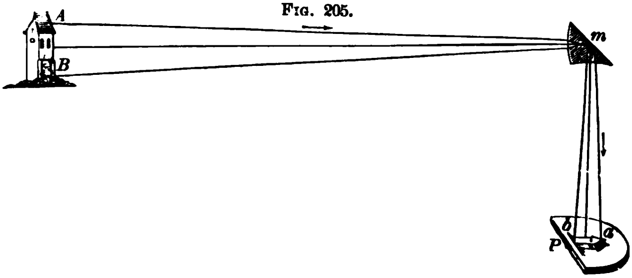


Fig. 205 shows the course of the rays in forming the image. The rays coming from the object, AB, fall upon the convex face of the lens, and are converged, and in this state they reach the plane surface, m, which is inclined to the horizon. Being totally reflected from the surface, m, they emerge through the slightly concave surface below, and go to form an image, ab, on the table P. A sheet of paper is spread on P to receive the image, and on it the outlines may be traced.

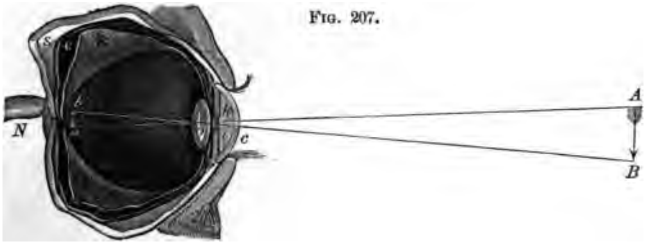
FIG. 206.

Photographer's Camera.

The Camera. The camera, used by photographers, contains a double-convex lens, L, which throws an inverted image of the object upon a removable ground-glass screen, S. When the focus has been obtained, the screen is removed, and a *slide, containing* a sensitive film, is inserted in its place.

The eye is a unique optical instrument resembling a camera. The outer membrane is termed the sclerotic coat, *S* (Fig. 207). It is tough, white, opaque, and firm. A little portion in front, called the cornea, *c*, is more convex and perfectly transparent. The middle or choroid coat, *C*, is soft and delicate, like velvet. It lines the inner part of the eye and is covered with a black pigment. Over it the optic nerve, which enters at the rear, expands in a net-work of delicate fibers termed the retina, the seat of vision. Back of the cornea is a colored curtain, *hi*, the iris (rainbow), in which is a round hole called the pupil. The crystalline lens, *o*, is a double-convex lens, composed of concentric layers somewhat like an onion, weighing about four grains and

FIG. 207.



Vertical Section of the Eye.

transparent as glass. Between the cornea and the crystalline lens is a limpid fluid termed the aqueous humor; while the vitreous humor, a transparent, jelly-like liquid, fills the space back of the crystalline lens.

Let *AB* represent an object in front of the eye. Rays of light are first refracted by the cornea and aqueous humor, next by the crystalline lens, and last by the vitreous humor, forming on the retina an image, *ab*, which is real, inverted, and smaller than the object. Euclid and Plato, however, thought that the ray of light proceeds from the eye to the object, an error that was long uncorrected. One thousand years did not bring much advancement in this department of knowledge.

The diameter of the eye is less than an inch; yet, as we look over an extended landscape, every feature, with all its variety of shade and color, is repeated in miniature on the retina. Millions upon millions of ether waves, converging from

every direction, break on that tiny beach, while we, oblivious to the marvelous nature of the act, think only of the beauty of the revelation. Yet in it the physicist sees a new illustration of the simplicity and perfection of the laws and methods of the Divine Workman, and a continued reminder of His forethought and skill.

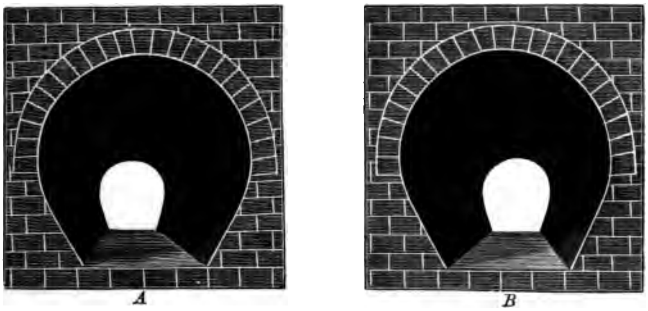
To render vision distinct, the rays must be accurately focused on the retina. If we gaze steadily at an object near by, and at the same time regard a distant object in the same direction, we find our vision of this blurred. If now we gaze at the more distant object, our vision of the nearer one becomes blurred. The eye thus has the power of adapting itself to the varying distances of objects. This is done by a change in the convexity of the front surface of the crystalline lens under the action of the ciliary muscle which surrounds it at its edges. When clear vision can not be had of distant objects, the person is near-sighted. When the ciliary muscle is strained to produce clear vision of objects less than ten or twelve inches distant, the person, if young, is over-sighted. In the first case, the distance of the retina from the crystalline lens is too great to permit of distinct focalization; in the second case, this distance is too small. The remedy for near-sightedness is to wear concave glasses, selected by a competent oculist. Rays from distant objects are thus made to diverge before entering the eye, as if they had come from very near objects. For over-sightedness, the remedy is properly selected convex glasses.

There are other defects for which the aid of the oculist should be sought. If glasses are needed, they should never be selected except after examination by a thoroughly competent person. If not properly adapted, they may do much more harm than good. No eye is optically perfect, and but few are free from defects that may be detected on examination. That glasses are more used now than during the previous generations is due not so much to increase of habits injurious to vision as to the better knowledge of the eye and the better opportunities for every person to find out his own defects.

As old age approaches, the crystalline lens becomes less elastic, so that the eye loses the power of accommodation to near objects. Convex glasses become necessary for reading, while the vision of distant objects may remain perfect.

The retina retains an impression for a brief time after the object has been removed, usually a fraction of a second, which varies according to the brightness. This explains why a lighted coal, rapidly moved in the dark, appears as a line of light. When one is riding slowly on the cars and looking at the landscape between the upright fence-boards, he catches only glimpses of the view; but when moving rapidly, these snatches will combine to form a perfect landscape, which has, however, a grayish tint, owing to the decreased amount of light reflected to the eye. Many of the most brilliant effects from fire-works

FIG. 208.



A Stereograph which may be viewed without a Stereoscope.

depend on this property of the retina. The Zoetrope is an instrument by which a succession of pictures of the same object in different phases of motion are made to pass rapidly before the eye. The persistence of the successive sensations causes an apparent blending, so that the illusion is that of an object actually in motion.

Binocular Vision.

In looking with both eyes at an object that is not very distant, we obtain a much better idea of its position and form, or its "depth in space," than when a single eye is employed. The two retinal images differ slightly because the two eyes are different in direction from the object, and hence to a slight extent we see around the object on two sides. The illusion of depth in space is well brought out by means of Fig. 208. The tunnel, A, appears as if viewed by the left eye alone; *B*, as if by the right eye

alone. Bring the page close up to the face, so that one picture is immediately in front of each eye. The two images at once seem combined into a single blurred image. Now withdraw the page a few inches; the haziness gives place to distinctness and the tunnel appears startlingly deep, as if it were a hole through the book. While still gazing into its depths two more tunnels may be indirectly seen, one on each side of it; but the illusion of depth in them is far less clear. Each is seen by but a single eye, while the middle one is a binocular perception.

In performing this experiment, it is very important to avoid crossing the eyes. Perfect relaxation of the muscles of the eyeballs will make it very easy. Imagine yourself to be looking through the page at the opening of a distant tunnel, and keep the muscles relaxed.

For further discussion of the stereoscope, consult an article on this subject in the *Popular Science Monthly* for May and June, 1882.

The stereoscope is an instrument intended to aid in attaining binocular vision of a pair of properly prepared pictures, which together compose the stereograph. With a little practice like that just described, any one may become independent of the stereoscope.

CHAPTER VIII.

ON HEAT.

"The combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 lbs. of coal is equivalent to the work of an able-bodied man for a life-time."

PRODUCTION OF HEAT.

Definitions.

Radiant Energy is the name of what we receive from the sun, stars, and other heated bodies. It may be manifested as light, as temperature, as chemism, or in all of these ways at the same time.

Early Theories.

Democritus, the originator of the Atomic Theory, held that heat consists of minute spherical particles radiated rapidly enough to penetrate every substance. Until very recently, heat and light were thus reckoned among the Imponderables, *i. e.*, matter which has no weight. Aristotle considered heat more a condition than a substance. Bacon, in his "Novum Organum," wrote: "Heat is a motion of expansion." Locke, half a century later, said: "Heat is a very brisk agitation of the insensible parts of an object, which produces in us the sensation from whence we denominate the object hot, so that what in our sensation is heat, in the object is motion."

The material view, however, held its ground. At the beginning of the 18th century, Stahl elaborated a theory that a buoyant substance called phlogiston is the principle of heat, and that when a body burns, its phlogiston escapes as fire. In 1760, Dr. Black investigated and made known the principles of what he termed latent heat, *i. e.*, heat which becomes hidden when ice is turned into water or water into steam. Priestley

discovered, in 1774, and Lavoisier afterward developed, the modern view of combustion. But the latter philosopher then advanced the theory that heat (caloric) is an actual substance, which passes freely from one body to another and combines at pleasure. Toward the close of the 18th century, Benjamin Thompson, better known as Count Rumford, a native of Woburn, Mass., but in the employ of the Elector of Bavaria, proved the convertibility of force. "He first took the subject," as Professor Youmans well remarks, "out of the domain of metaphysics, where it had been speculated upon since the time of Aristotle, and placed it on the true basis of physical experiment."

Soon the scientific world seemed to be ripe for this discovery, and it appears to have sprung up spontaneously in men's thoughts every-where. Mayer, a physician of Germany, and Grove, of England, proved the mutual relation of the forces, the latter first using the term "Correlation of Forces," since changed to Conservation of Energy. Joule discovered the law of the "Mechanical Equivalent of Heat," about 1843.

In his famous experiments, he used pound-weights made to fall through a measured distance. Cords were attached to them, so that, as they fell, they turned a paddle-wheel placed in a box of water. Other liquids were used instead of the water. The rise of temperature in the liquids was carefully marked. The loss by friction in the apparatus was estimated, and so, at last, the dynamical theory of heat was fully demonstrated. Names of philosophers well-known to us, such as Henry, Helmholtz, Faraday, Thomson, Maxwell, Le Conte, Youmans, Stewart, and Tyndall, are associated with the final establishment of this theory.

Relation between the Forms of Radiant Energy.

Thrust a cold iron into the fire. It is at first dark, but soon becomes luminous, like the glowing coals.—Raise the temperature of a platinum wire. We quickly feel the radiation of obscure heat-rays. As the metal begins to glow, our eyes detect a red color, then orange combined with it, and so on through the spectrum. At last all the colors are emitted, and the metal is *dazzling* white. Like light, heat may be reflected, refracted, *and polarized*. It radiates in straight lines in every direction,

and decreases in intensity as the square of the distance increases. It moves with the same velocity as light.

It is believed that each of the forms of radiant energy is merely the manifestation of wave-motion at a special rate. The longer and slower waves of ether fall upon the nerves of touch, and produce the sensation of heat. The more rapid affect the optic nerve and produce the sensation of light. The shortest and quickest cause chemical changes.

According to Tyndall, 95 per cent. of the rays from a candle are invisible, or heat-rays. These may be brought to a focus and bodies fired in the darkness.—Each of the five classes of nerves seems to be adapted to transmit vibrations of its own kind, while it is insensible to the others. Thus, if the rate of oscillation be less than that of red, or more than that of violet, the optic nerve is uninfluenced by the waves. We can not see with our fingers, taste with our ears, or hear with our nose. Yet these are organs of sensation and sensitive to their peculiar impressions.

"Suppose, by a wild stretch of imagination, some mechanism that will make a rod turn round one of its ends, quite slowly at first, but then faster and faster, till it will revolve any number of times in a second; which is, of course, perfectly imaginable, though you could not find such a rod or put together such a mechanism. Let the whirling go on in a dark room, and suppose a man there knowing nothing of the rod; how will he be affected by it? So long as it turns but a few times in the second, he will not be affected at all unless he is near enough to receive a blow on the skin. But as soon as it begins to spin from sixteen to twenty times a second, a deep growling note will break in upon him through his ear; and as the rate then grows swifter, the tone will go on becoming less and less grave, and soon more and more acute, till it will reach a pitch of shrillness hardly to be borne, when the speed has to be counted by tens of thousands. At length, about the stage of forty thousand revolutions a second, more or less, the shrillness will pass into stillness; silence will again reign as at first, nor any more be broken.

"The rod *might now* plunge on in mad fury for a long time *without making any* difference to the man; but let it suddenly

come to whirl some million times a second, and then through intervening space faint rays of heat will begin to steal toward him, setting up a feeling of warmth in his skin; which again will grow more and more intense, as now through tens and hundreds and thousands of millions the rate of revolution is supposed to rise. Why not billions? The heat at first will be only so much the greater. But, lo! about the stage of four hundred billions there is more—a dim red light becomes visible in the gloom; and now, while the rate still mounts up, the heat in its turn dies away, till it vanishes as the sound vanished; but the red light will have passed for the eye into a yellow, a green, a blue, and, last of all, a violet. And to the violet, the revolutions being now about eight hundred billions a second, there will succeed darkness—night, as in the beginning. This darkness, too, like the stillness, will never more be broken. Let the rod whirl on as it may, its doings can not come within the ken of that man's senses."

Theory of Heat.

Heat is motion. The molecules of a solid are in constant vibration. When we increase the rapidity of this oscillation, we heat the body; when we decrease it, we cool the body. The vacant spaces between the molecules are filled with ether. As the air moving among the limbs of a tree sets its boughs in motion, and in turn may be kept in motion by the waving of branches, so the ether puts the molecules in vibration, or is thrown into vibration by them.

Insert one end of a poker in the fire. The particles immersed in the flame are made to vibrate intensely; the swinging molecules strike their neighbors, and so on, continually, until the oscillation reaches the other end. If we handle the poker, the motion is imparted to the delicate nerves of touch; they carry it to the brain, and pain is felt. In popular language, "the iron is hot," and we are burned. If, without touching it, we hold our hand near the poker, the ether-waves set in motion by the vibrating molecules of iron strike against the hand, and produce a less intense sensation of heat. In the former case, the fierce motion is imparted directly; in the latter, the ether acts as a carrier to bring it to us.

The sources of heat are the sun, the stars, and mechanical and *chemical* energy.

The Sources of Heat.

The molecules of the sun and stars are in rapid vibration. These set in motion waves of ether, which are propagated across the intervening space, and meeting the earth, give up their motion to it. Friction and percussion produce heat, the motion of a mass being changed into motion among molecules. A horse hits his shoe against a stone and "strikes fire"; little particles of the metal being torn off are heated by the shock, and some of the energy is manifested also as light. A train of cars is stopped by the pressure of the brakes. In a dark night, we see the sparks flying from the wheels, the motion of the train being converted into heat. A blacksmith pounds a piece of iron until it glows. His strokes set the particles of metal vibrating rapidly enough to send ether-waves of such swiftness as to affect the eye of the observer. As a cannon-shot strikes an iron target, a shower of sparks is scattered around. Were the earth instantly stopped, enough heat would be produced to "raise a lead ball the size of our globe to 384,000° C." If it were to fall to the sun its impact would produce a thousand times more heat than its burning. Chemical action is seen in fire. The oxygen of the air has an affinity for the carbon and hydrogen of the fuel. They combine, and chemical energy is transformed into that of sensible heat.

Mechanical Equivalent of Heat.

In these various changes of mechanical motion into motion of molecules no energy is destroyed, though some of it may be so transformed as to become incapable of being made to do useful work. If the energy transformed by the fall of a blacksmith's hammer on his anvil could be gathered up, it would be sufficient to lift the hammer to the point from which it fell.

A pound-weight falling vertically 772 feet, will generate enough heat to raise the temperature of one pound of water through 1° F.; conversely, this amount of heat is the equivalent of the energy required to lift one pound mechanically to a height of 772 feet. This important truth was first demonstrated by Mr. Joule, of Manchester, England, and we express it by saying 772 foot-pounds is the mechanical equivalent of heat. Expressed in metric measures, it is 424 kilogram-meters for 1° C.

PHYSICAL EFFECTS OF HEAT.

Expansion. If the molecules of a body have an increase of energy imparted to them they swing, like pendulums, through wider arcs. Each tends to push against its neighbor, and the mass as a whole grows larger. Hence the general law, "Heat expands and cold contracts," cold being merely a relative term implying the withdrawal of energy. The ratio of the increase of volume to the original volume for a change of 1° in temperature is called the Coefficient of Expansion. Generally this is greatest for gases, — especially well illustrated in the gas well, Fig. 209,—less for liquids, and least for solids, each particular substance having its own coefficient. The force of expansion is for many substances irresistible. A rise in temperature of 80° F. will lengthen a bar of wrought-iron, 10 feet long, about $\frac{1}{17}$ of an inch; and if its cross-section is one square inch it will push in expanding with a force of about 25 tons. When the metal cools it will contract with the same force.

Fig. 209.

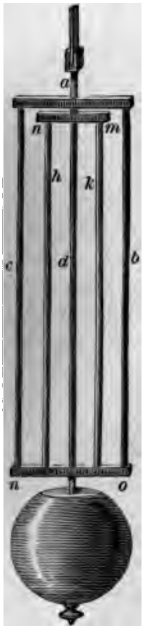
Gas Well.

A carriage-tire is put on when hot, in order that, when cooled, it may bind the wheel together.—Rivets used in fastening the plates of steam-boilers are inserted red-hot.—"The ponderous iron tubes of the Britannia Bridge writhe and twist, like a huge serpent, under the varying influence of the solar heat. A span of the tube is depressed only a quarter of an inch by the heaviest train of cars, while the sun lifts it $2\frac{1}{2}$ inches." The same may be noticed on the great Brooklyn Bridge, more than a mile long, where an allowance f nearly a yard has to be made for expansion with the change ' *seasons.* The Bunker-hill monument nods as it follows the n *in its daily* course. Tumblers of thick glass break on the

sudden application of heat, because the surface dilates before the heat has time to be conducted to the interior.

A familiar application of expansion is in the pendulum of a clock, which lengthens in summer and shortens in winter. A clock, therefore, tends to lose time in summer and gain in winter. To regulate it we raise or lower the pendulum-bob.

FIG. 210.



Gridiron Pendulum.

The gridiron pendulum consists of brass and steel rods, so connected that the brass, *h*, *k*, will lengthen upward, and the steel, *a*, *b*, *c*, *d*, downward, and thus the center of oscillation remain unchanged. The mercurial pendulum contains a cup of mercury which expands upward, while the pendulum-rod expands downward.

Temperature.

When one body is in a condition to communicate heat to another, the first is said to have a higher temperature than the second, or to be warmer. We measure temperature usually by noting its effect in producing expansion. Within narrow limits we may form a rough estimate of it by the sensation of touch, but this method of calculating temperature is very unreliable.

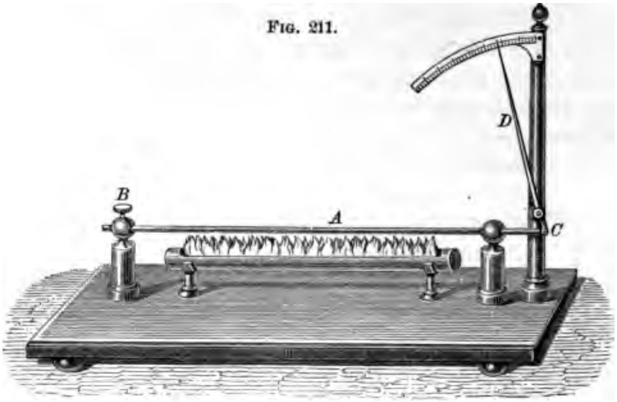
Expansion of Metals.

Fig. 211 represents the method of showing and measuring the linear expansion of the metals by means of an instrument called the pyrometer. A rod of metal, *A*, passes through two metallic supports, being made fast at one extremity by a clamp-screw, *B*, and being free to expand at the other extremity. The free end abuts against the short end, *C*, of a lever, the long end, *D*, of which plays in front of a graduated arc.

When the rod is heated, by placing fire beneath it as shown in the figure, the rod, *A*, expands, and the expansion is shown by the motion of the index, *D*. When the rod, *A*, is of steel, copper, silver, etc., the amount of expansion varies, as is shown by the dif ferent amounts of displacement of the index. Brass, for exampl expands more, for the same amount of heat, than iron or ste

Fig. 212 shows the method of demonstrating that bodi

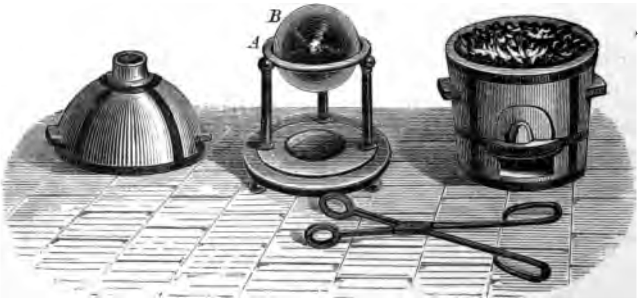
FIG. 211.



The Pyrometer.

undergo an expansion in volume when heated. A ring, A, is constructed so that a ball, B, passes freely through it when cold. If the ball be heated in a furnace, it will no longer pass through the ring; but if allowed to cool, it again falls through the ring. The experiment is fully shown in the figure.

FIG. 212.



Ring to show Expansion.

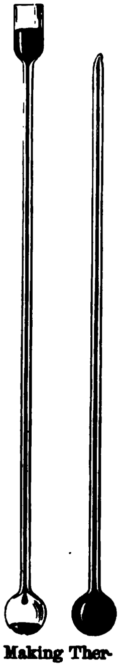
Unequal Expansion of Metals. In Fig. 213 we have shown a simple contrivance for illustrating the unequal expansion of different metals. Two bars of iron and brass are riveted together at different points along their whole length, forming *one compound* bar.

When such a bar is heated, the brass expands more than the iron, and the bar curves, as represented in Fig. 213, in

Fig. 213.

order to accommodate the inequality of length which thus results. When the bar has returned to its original temperature, it assumes its rectilinear form, to bend again in the opposite direction if it be afterward subjected to cooling. The unequal expansion of different metals is also shown in the compensation pendulum, page 193.

Figs. 214, 215.



Making Thermometers.

The thermometer is an instrument for measuring temperature, by the expansion of mercury or alcohol.

Method of making a Thermometer.

A capillary tube of glass is provided, of uniform bore, upon one end of which a bulb is blown, and upon the other a funnel, as shown in Fig. 214.

The funnel is nearly filled with mercury, which is at first prevented from penetrating into the bulb by the resistance of the air and the smallness of the tube. The bulb is therefore heated, when the air within expands, and a portion escapes in bubbles through the mercury. On cooling, the pressure of the external atmosphere forces a quantity of mercury through the tube into the bulb. By repeating this operation a few times, the bulb and a portion of the tube are filled with mercury.

The whole is then heated till the mercury boils, thus filling the tube, when the funnel is melted off and the tube hermetically sealed by means of a jet of flame urged by a blow-pipe. On cooling, the mercury descends to some point of the tube, as shown in Fig. 215, leaving a vacuum at the upper end. All that remains to be done is to graduate it, and attach a suitable scale.

Two points of the stem are first determined, the freezin-

and the boiling points. These are determined on the principle that the temperatures at which distilled water freezes and boils are always constant, that is, when these changes of state take place under equal atmospheric pressures.

Method of Graduation.

FIG. 216.

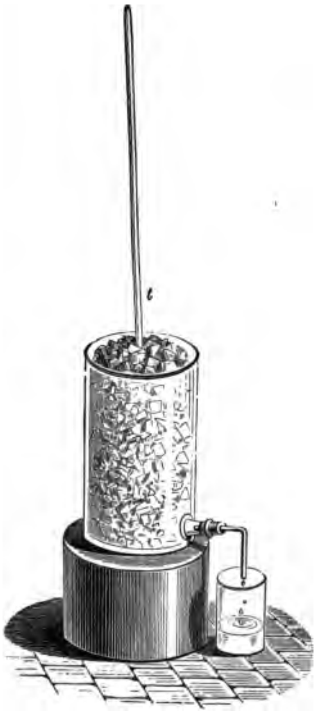


FIG. 217.

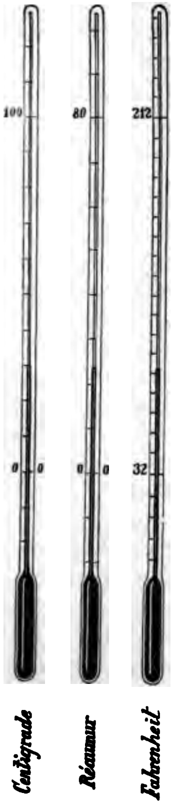
Testing Thermometers.

The instrument is first plunged into a bath of melting ice, as shown in Fig. 216, and is allowed to remain until it takes the temperature of the mixture, say twenty or thirty minutes. A slight scratch is then made on the stem at the upper surface *of the mercury*, and this constitutes the freezing-point.

The instrument is next plunged into a bath of distilled

water, in a state of ebullition, care being taken to surround it with steam by means of an apparatus like that shown in Fig. 217. After the mercury ceases to rise in the tube, which will be in a few minutes, the level of its upper surface is marked on the stem by a scratch, as before, and this constitutes the boiling-point.

Fig. 218.



The space between the boiling and freezing points is then divided into a certain number of equal parts, and the graduation is continued above and below as far as may be desired. These divisions may be scratched upon the glass with a diamond, or, as is usually done, they may be made on a strip of metal, which is attached to the frame. The divisions are numbered according to the kind of scale adopted.

Thermometric Scales.

Three principal scales are used: the Centigrade scale, in which the space between the freezing and boiling points is divided into 100 equal parts, called degrees; Réaumur's scale, in which the same space is divided into 80 equal parts, called degrees; and Fahrenheit's scale, in which this space is divided into 180 equal parts, also called degrees.

In the Centigrade scale, the freezing-point is marked 0, and the degrees are numbered both up and down, the former numbers being considered positive, and designated by the sign +, whilst the latter are considered negative, and designated by the sign −. Of course the boiling-point is marked 100°.

The signs + and − are used also in Réaumur's and Fahrenheit's thermometers to indicate degrees respectively above and below the zero-point.

In Réaumur's scale, the freezing-point is marked 0, and the boiling-point 80°. The degrees below freezing are marked as in the Centigrade scale.

In Fahrenheit's scale, *which is the one principally used in the United States,* the zero-point is taken 32° below the freezing

point, and the divisions are numbered from this point both up and down. The boiling-point of distilled water is 212°. The inventor placed zero 32° below the temperature of freezing water, because he thought that to be absolute cold—a point now estimated to be about 492° below the freezing-point on his scale. The following formulæ will be of use in comparing the readings of the different scales:

$$R. = \tfrac{4}{5}\ C. = \tfrac{4}{9}\ (F. - 32^\circ). \qquad (1.)$$
$$C. = \tfrac{5}{4}\ R. = \tfrac{5}{9}\ (F. - 32^\circ) \qquad (2.)$$
$$F. = \tfrac{9}{5}\ C. + 32^\circ = \tfrac{9}{4}\ R. + 32^\circ \qquad (3.)$$
$$1^\circ\ C. = 1.8^\circ\ F. \qquad (4.)$$

The Heat Unit.

For measuring quantity of heat, the unit commonly employed in England and America is that quantity which is required to raise the temperature of one pound (avoirdupois) of water through one degree (Fahrenheit) above the freezing-point.

Liquefaction or Fusion.

When heat is communicated to a solid body, a point is finally reached when the vibratory swing of its molecules is so great that they are driven apart, each toward the limit of the sphere of attraction of its neighbor, so that all rigidity is lost. The molecules then move freely among themselves. The energy that is applied raises the temperature of the body up to a fixed point called its melting or fusing point, when liquefaction begins. Additional energy then does the work of driving the molecules apart without further rise of temperature, until fusion is complete; after which the liquid rises still further in temperature. This is true only of bodies which are not broken into their chemical constituents before the meeting-point is reached. A large variety of substances, such as wood, bone, flesh, etc., become chemically changed instead of melting.

Energy that does thus the work of changing the state of a body without at the same time changing its temperature is often called latent heat, a term which is gradually going out of use. If a pound of ice at 32° F. be heated, it requires 142 heat units to melt it, and 180 more to raise its temperature then up to the boiling-point.

The converse of fusion is freezing. Ice melts at 32° F., and in doing so it absorbs energy. Water freezes at 32° F., and in

doing so it gives out the energy which had been keeping its molecules apart. Thawing is thus a cooling process and freezing is a warming process. Freezing mixtures depend on this principle. In freezing ice-cream, salt and pounded ice are put around the vessel that contains the cream. The strong attraction between salt and water causes the ice to melt rapidly, and the solid salt becomes liquid by solution. This rapid thawing involves much absorption of energy, which comes from the nearest objects whose temperature is higher than that of the solution. The cream thus loses energy, its temperature becoming reduced down to the freezing-point.

That freezing is a warming process may be conclusively shown as follows: Gently melt some sodium sulphate (a cheap salt that may be obtained from any apothecary) in a flask by heating it over a lamp flame. Put it aside to cool slowly in a perfectly quiet place. After cooling it remains liquid, but ready to freeze as soon as motion among its molecules is started. Disturb it by putting a thermometer bulb into the liquid. At once crystals are seen shooting out, and the mass is soon frozen hard. The mercury in the thermometer meanwhile rises, and the warming may be felt with the hand.

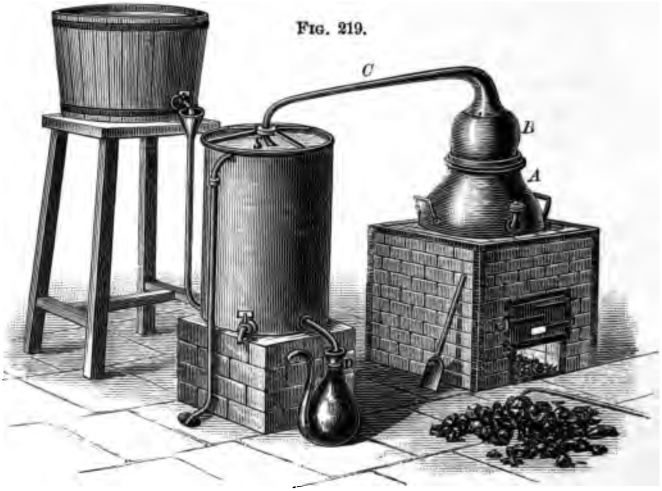
Vaporization.

When heat is applied to a liquid, the temperature rises until the boiling-point is reached, when it stops and the liquid is changed to vapor at that constant temperature. The vapor is nearly free from solids dissolved in the liquid. Pure or distilled water is obtained by heating water in a boiler, *A* (Fig. 219), whence the steam passes through the pipe, *C*, and the worm within the condenser, *S*, where it is condensed and drops into the vessel, *D*. The pipe is coiled in a spiral form within the condenser, and is hence termed the worm. The condenser is kept full of cold water from the tub at the left. By carefully regulating the temperature, one liquid may be separated from another by "fractional" distillation, advantage being taken of the fact that each liquid has its own boiling-point, higher or lower than that of the liquid with which it is mixed.

When we heat water, the bubbles which pass off first are *the air dissolved in the liquid*; next bubbles of steam form on *the bottom and sides of* the vessels, and, rising a little distance,

are condensed by the cold water. Collapsing, they produce the sound known as "simmering." As the temperature of the water rises, they ascend higher, until they burst at the surface, and pass off into the air. The violent agitation of the water thus produced is termed boiling. The temperature of water can not be raised above the boiling-point, unless the steam be confined. The extra energy is applied in expanding the water into steam. This occupies 1,700 times the space, and is of the same

FIG. 219.



A Still.

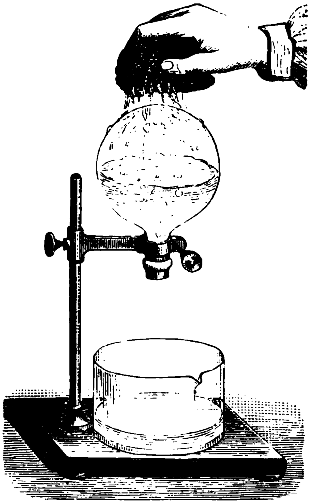
temperature as the water from which it is made. Nearly 1,000° units of heat for each pound of water are expended in this process, but are made sensible again as temperature when the steam is condensed. Steam is invisible. This we can verify by examining it where it issues from the spout of the tea-kettle. It soon condenses, however, into minute globules, which become visible in white clouds.

Some substances vaporize at ordinary temperatures; others only at the highest; while the gases of the air are but the vapor of substances which boil at exceedingly low temperatures. *The distinction* between gases and vapors in ordinary *language is only* relative.

The boiling-point of water depends on circumstances. A solid substance dissolved in water ordinarily elevates the boiling-point. Thus salt water boils at a higher temperature than pure water. The air dissolved in water tends by its elastic force to separate the molecules. If this be removed, the boiling-point may be elevated to 275° F., when the water will be converted into steam with explosive violence.

Water will boil at a lower temperature in iron than in glass. When the surface of the glass is chemically clean, the boiling-point is still higher. This seems to depend in some degree on the strength of the adhesion between the water and the containing vessel.

Fig. 220.



Boiling Water by Condensing its Vapor.

"Pressure upon the surface raises the boiling-point. Water, therefore, boils at a lower temperature on a mountain than in a valley. Pressure opposes the repellent heat-force, and so renders it easier for cohesion to hold the particles together. In the interior of the earth there may be masses of matter heated red or white hot and yet solid, more rigid even than glass, in consequence of their melting-point being raised so high by the tremendous pressure that they can not liquefy."—Tait.

The temperature of boiling water at Quito is 194° F., and on Mont Blanc, 183° F. The variation is so uniform that the height of a place can thus be ascertained; an ascent of 596 feet producing a difference of 1° F.

The influence of pressure is well illustrated by the following experiment: Half fill a strong glass flask with water, and boil this until all the air is expelled from both the water and the space above it. Now quickly apply a tight stopper and invert. The *pressure of the steam* will stop ebullition. A few drops of *cold water will* condense the steam, and boiling will recom

mence. This will soon be checked, but can be restored as before. The process may be repeated until the water cools to the ordinary temperature of the air, and even then the liquid inside may be made to boil by rubbing the outside of the flask with ice. The cushion of air which commonly breaks the fall of water is removed, and if the cork be air-tight, the water, when cold, will strike against the flask with a sharp, metallic sound.

Evaporation. Evaporation is a slow formation of vapor, which takes place at ordinary temperatures. Water evaporates even at the freezing-point. Clothes dry in the open air in the coldest weather. The wind quickens the process, because it drives away the moist air near the clothes and supplies dry air. Evaporation is also hastened by an increase of surface and a gentle heat.

Vacuum pans are employed in condensing milk and in the manufacture of sugar. They are so arranged that the air above the liquid in the vessel may be exhausted, and then the evaporation takes place rapidly, and at so low a temperature that burning is avoided.

The cooling effect of evaporation is due to the absorption of energy required to drive the molecules apart beyond their spheres of mutual attraction. Water may be frozen under the receiver of an air-pump by placing a small watch-glass containing it over a pan of strong sulphuric acid, which absorbs the vapor as fast as it is formed in the vacuum. The cooling due to rapid evaporation of a part is sufficient to freeze the rest. By strong pressure and cooling, carbonic acid is easily liquefied. Allowing a jet of this liquid to escape, the evaporation of a part of it causes the rest to freeze into a snowy powder which may be pressed into a ball.

Mercury in contact with it is quickly solidified. On throwing the frozen metal into a little water, the mercury instantly liquefies, but the water turns to ice, the solid thus becoming a liquid and the liquid a solid by the exchange of heat. A cold knife cuts through the mass of frozen mercury as a hot knife would ordinarily through butter. The author, on one occasion, saw *Tyndall*, during a course of lectures at the Royal Institution *London*, when freezing a ladle of mercury in a red-hot cru-

cible, add some ether to hasten the evaporation. The liquid caught fire, but the metal was drawn out from the glowing crucible, through the midst of the flame, frozen into a solid mass.

Nitrogen, oxygen, and air, which is a mixture chiefly of these two gases, have been liquefied. Liquid air boils at − 337° F. in a vacuum. Nitrogen has been obtained in "snow-like crystals of remarkable size," and by reducing the pressure on these a temperature of − 373° F. was obtained,—the lowest recorded up to the present date (1889).

Spheroidal State.

If a few drops of water be put in a hot, bright spoon, they will gather in a globule, which will dart to and fro over the surface. It rests on a cushion of steam, while the currents of air drive it about. If the spoon cool, the water will lose its spheroidal form, and coming into contact with the metal, burst into steam with a slight explosion. Drops of water spilled on a hot stove, illustrate the principle.—By moistening the finger, we can touch a hot flat-iron with impunity. The water assumes this state, and thus protects the flesh from injury.—Furnace-men can dip their moistened hands into molten iron.

Specific Heat.

More energy is required to raise the temperature of a pound of water through one degree than for any other substance except the gas hydrogen. The fraction of a heat unit required to produce an equal change of temperature in any other substance is called its specific heat; thus for mercury it is about $\frac{1}{30}$; for iron, $\frac{1}{9}$; for air, nearly $\frac{1}{4}$; for hydrogen, $3\frac{4}{10}$. On this account the ocean changes its temperature far less quickly than the land, and sea-side cities are subject to less extremes of temperature than those on the middle of a continent. On the elevated plateau region around the Great Salt Lake the temperature during the year varies from 115° F. to − 30° F.

COMMUNICATION OF HEAT.

Heat tends to become diffused equally among neighboring *bodies. There are three* modes of distribution. If we touch a *object colder than* we are, it abstracts heat from us, and w

say "it feels cold"; if a warmer body, it imparts heat to us, and we say "it feels warm." Adjacent objects have, however, the same temperature, though flannel sheets feel warm, and linen cold. These effects depend upon the relative conducting power of different substances. Iron feels colder than feathers, because it robs us faster of our heat.

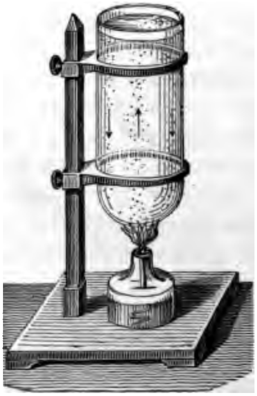
Heat.

Conduction is the process of heating by the passage of heat from molecule to molecule. Hold one end of a poker in the fire, and the other end soon becomes hot enough to burn the hand. Of the ordinary metals, silver and copper are the best conductors. Place a silver, a German-silver, and an iron spoon in a dish of hot water. Notice how much sooner the handle of the silver spoon is heated than the others. Wood is a poor conductor, especially "across the grain."

Conduction.

Gases are the poorest conductors; hence porous bodies, as wool, fur, snow, charcoal, etc., which contain large quantities of air, are excellent non-conductors. Refrigerators and ice-houses have double walls, filled between with charcoal, sawdust, or other non-conducting substances. Air is so poor a conductor that persons have gone into ovens that were hot enough to cook meat, which they carried in and laid on the metal shelves; yet, so long as they did not themselves touch any good conductor, they experienced little inconvenience.

FIG. 221.



Heating by Convection.

Liquids are also poor conductors. Hold the upper end of a test-tube of water in the flame of a lamp. The water nearest the blaze will boil without the heat being felt by the hand.

Convection is the process of heating by circulation. Place a little sawdust in a flask of water, and apply heat. We shall soon find that an *ascending* and *descending* current are established. The water near the lamp

Convection.

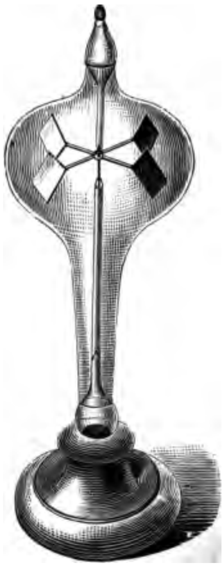
becoming heated, expands and rises. The cold water above sinks to take its place.

By testing with a lighted candle, we shall find at the bottom of a door opening into cold air, a current setting inward, and at the top, one setting outward. The cold air in a room flows to the stove along the floor, is heated, and then rises to the ceiling. Heating by hot-air furnaces depends upon the principle that warm air rises.

Radiation.

Radiation is the transmission of rays in straight lines by the vibration of the ether. The heat from the sun comes to the earth in this manner. A hot stove radiates heat. Rays of heat do not always elevate the temperature of the medium through which they pass. When the motion of the ether-waves is stopped, the effect is felt. The Radiometer is an instrument that, for a time, was supposed to exhibit the actual mechanical force of the sunbeam. It consists of a tiny vane delicately pivoted in a glass globe from which the air is exhausted as fully as possible, when the globe is hermetically sealed. The four arms of the vane carry each a thin light disk of mica or aluminium, covered with lamp-black on one side and uncovered on the other. When daylight falls upon it the little vane revolves rapidly. The motion ceases as soon as the light is cut off. When different gases are admitted into the globe, the rate of rotation varies. It is now believed that the unequal heating of the black and white surfaces of the disks causes unequal reaction of the molecules of air left in the vacuum. Lamp-black being the best absorber and radiator, receives the more forcible bombardment of flying air molecules.

FIG. 222.

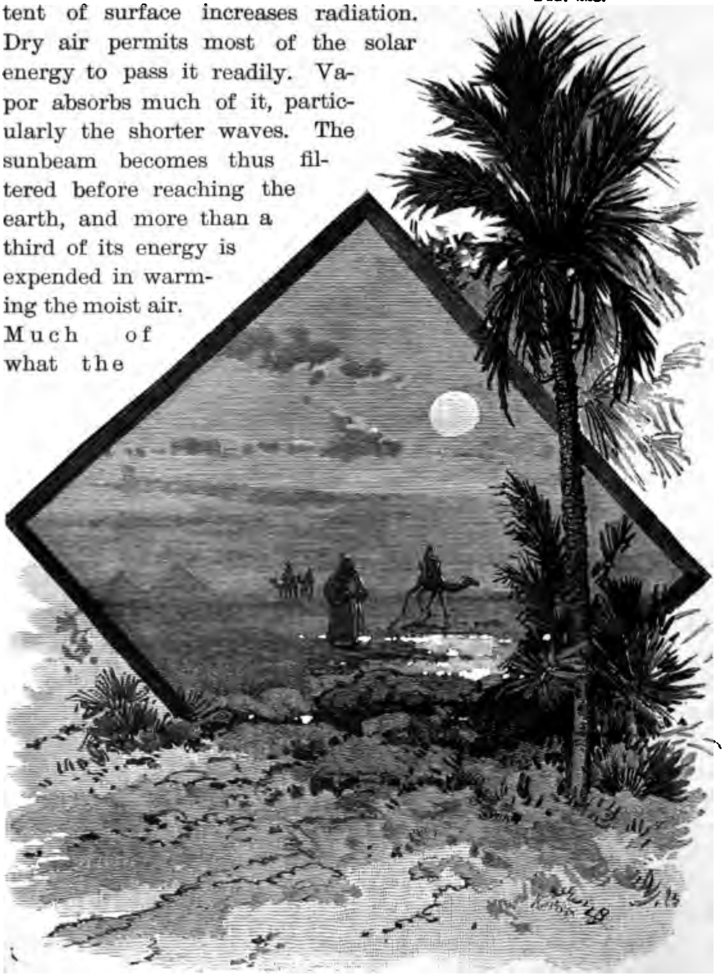


The Radiometer.

Space between the earth and the sun *is not warmed by the* sunbeam. Meat *can be cooked by radiation*, while the air around is at t

freezing-point. A rough, unpolished surface is a better radiator than a smooth, bright one. Extent of surface increases radiation. Dry air permits most of the solar energy to pass it readily. Vapor absorbs much of it, particularly the shorter waves. The sunbeam becomes thus filtered before reaching the earth, and more than a third of its energy is expended in warming the moist air. Much of what the

FIG. 228.



Desert.

earth absorbs is radiated forth again, but in much longer waves. This is especially true of the wide arid plains called

deserts, Fig. 223. To these water vapor is nearly opaque, as are also plates of glass. These are therefore used for the roofs of greenhouses to keep the plants warm inside.

In the course of Prof. Langley's experiments upon Mount Whitney, water was boiled by exposing it in a copper vessel covered by a pane of window-glass, to the direct rays of the sun. This shows that many of the heat-rays of the sunbeam are stricken down by the air before reaching low levels, but may be utilized at high elevations. So, were the atmosphere removed, the earth would receive far more heat and yet be much colder than now, because there would be no beds of water vapor to check the radiation back into space.*

At lofty elevations, like the great plateaus of Central Asia, the dry air allows the heat received by the soil during the day to escape so rapidly that a freezing temperature is felt before the night is ended; and this in turn is followed by torrid heat in the early afternoon.

Absorption and Reflection.

A good absorber is also a good radiator, but a good reflector can be neither. Snow is a good reflector, but a poor absorber or radiator. Light colors often absorb solar heat less and reflect more than dark colors. Experiments show that with artificial heat the molecular condition of the surface varies radiation as well as reflection. In fact, white lead is as good a radiator as lamp-black.—On one side of a sheet of paper paste letters of gold-leaf. Spread over the opposite side a thin coating of scarlet iodide of mercury—a salt which turns yellow on the application of heat. Turn the scarlet side down. Hold over the paper a red-hot iron. The gold-leaf will reflect the heat, but the paper spaces between the letters will absorb it, and on turning the paper over, the gilt letters will be found traced in scarlet on a yellow background.

White is generally considered the best reflector, and black the best absorber and radiator. But the nature of the material is of more importance than its tint. If on a bright summer day three thermometers are exposed to the sun, one held up in mid-air, another resting on a bed of black silk, and the third

* See *American Journal of Science*, March, 1883.

on a bed of white sand, it will be found in a short time that the temperatures indicated will be very different. The thermometer on the sand will have its bulb more warmed than that on the bed of black silk; and both of these will be warmer than the one in mid-air.

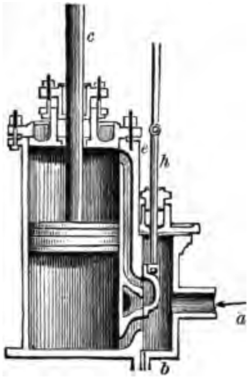
THE STEAM-ENGINE.

When steam rises from water at a temperature of 212°, it has an elastic force of nearly 15 lbs. per square inch. If the steam be confined and the temperature raised, the elastic force will be rapidly increased.

The Steam-engine.

The steam-engine is a machine for using the elastic force of steam as a motive power. There are two classes, high-pressure and low-pressure. In the former, the steam, after it has done its work, is forced out into the air; in the latter, it is condensed in a separate chamber by a spray of cold water. As the steam is condensed in the low-pressure engine, a vacuum is formed behind the piston; while the piston of the high-pressure engine acts against the pressure of the air.

Fig. 224.

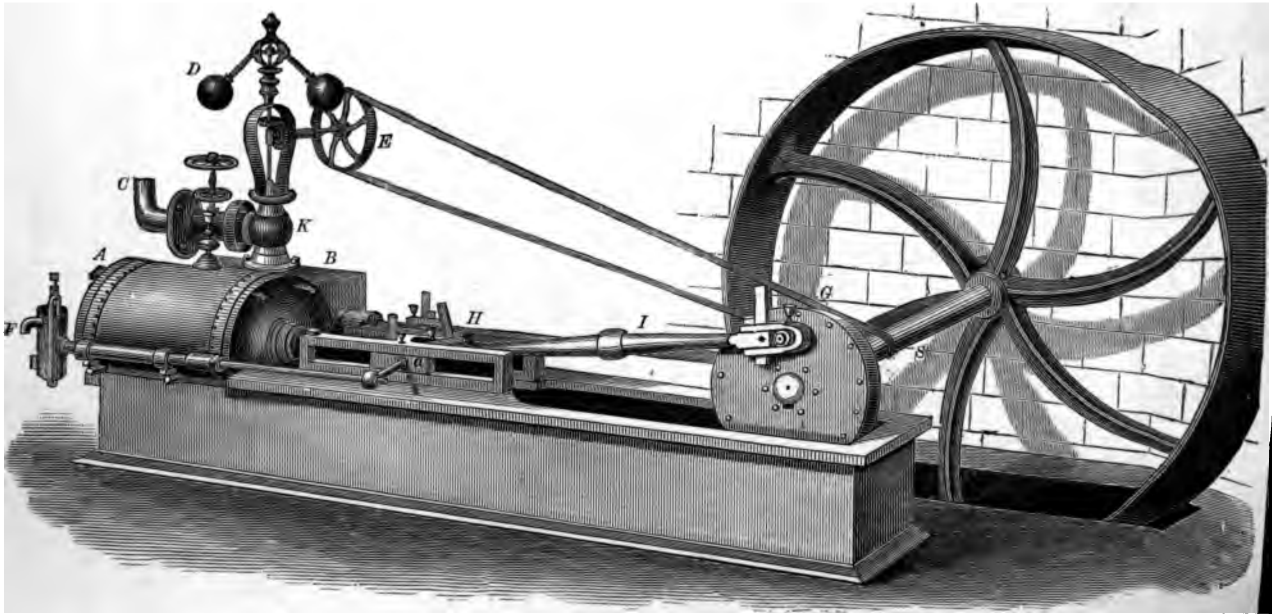


Steam-chest and Cylinder of an Engine.

The elastic force of the steam must be 15 lbs. per square inch greater in the latter case. The figure represents the piston and connecting pipes of an engine. The steam from the boiler passes through the pipe, *a*, into the steam-chest, *b*, as indicated by the arrow. The sliding-valve worked by the rod *h* lets the steam into the cylinder, alternately above and below the piston, which is thus made to play up and down by the expansive force. This valve is so arranged that at the moment fresh steam is let in on one side of the piston, the spent steam on the other side is released into the outer air, or into the condensing chamber.

The governor is an apparatus for regulating the supply of

Fig. 225.

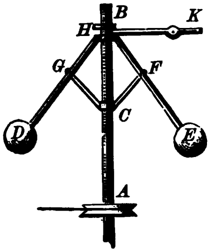


High-pressure Steam-engine.

steam. *AB* is the axis around which the heavy balls *E* and *D* revolve. They are so connected by hinge-joints that the ring at *B* may be pulled down or lifted by them, while that at *C* is fixed. When the machine is going too fast, the balls fly out and thus pull down the rod, *K*, which is in connection with a valve that controls the pipe supplying steam. A portion of the steam is thus obstructed, and the revolution of the balls becomes slower. This in turn makes them descend, and in so doing they lift the rod, *K*. The valve is thereby opened and more steam supplied, whenever the speed of revolution becomes too small.

The Governor.

FIG. 226.



The Governor.

A high-pressure engine is shown in Fig. 226. *A* represents the cylinder; *B*, the steam-chest at its side, connected with it on the interior by the sliding-valve already shown; *C*, the throttle-valve in the pipe through which steam is admitted from the boiler; *D*, the governor; *E*, the band-wheel by which the governor is driven; *F*, the pump; *G*, the crank; *I*, the conductor attached to *a*, the cross-head; *H*, the eccentric rod (*h* in Fig. 224) which works the sliding-valve in the steam-chest; *K*, the governor-valve; *S*, the shaft by which the power is conveyed to the machinery. The cross-head, *a*, slides to and fro in a groove, and is fastened to the rod which works the piston in the cylinder *A*. The expansive force of the steam is thus communicated to *a*, thence to *I*, by which the crank is turned. The heavy fly-wheel renders the motion uniform.

A High-pressure Engine.

METEOROLOGY.

The air always contains moisture. The amount it can receive depends upon the temperature; warm air absorbing more, and cold air less. At 100° F., a cubic foot of air can hold nearly 20 grains of *invisible water* vapor; a reduction of 70° will cause nine tenths *of that quantity* to be condensed into visible droplets. When

General Principles.

he air at any temperature contains all the vapor it can hold n an invisible state, it is said to be saturated; any fall of tem-)erature will then condense a part of the vapor.

FIG. 227.

Effect of Altitude on Vegetation.

When air expands against pressure (*i. e.*, doing work in the *xpansion), its energy,* being thus expended, ceases to be mani*sted as temperature.* The warm air from the earth ascendin

into the upper regions, is thus rarefied and cooled. Its vapor is then condensed into clouds, and often falls as rain. Owing to this expansion of the atmosphere and the greater radiation of heat in the dry air of the upper regions, there is a gradual diminution of the temperature as the altitude increases, the mean rate in the north temperate zone being about 1° for 300 feet.

Dew. The grass at night, becoming cooled by radiation, condenses the vapor of the adjacent air upon its surface. Dew will gather most freely upon the best radiators, as they will the soonest become cool. Thus grass, leaves, etc., receive the largest deposits. It will not form on windy nights, nor when there are clouds in the sky to reflect the heat radiated from the ground.

In tropical regions the nocturnal radiation on clear nights is often so great as to render the formation of ice possible. In Bengal, water is exposed for this purpose in shallow earthen dishes resting on rice straw. In parts of Chili, Arabia, etc., by its abundance, dew feebly supplies the place of rain. When the temperature of plants falls below 32°, the vapor is frozen upon them directly, and is called white, or hoar-frost.

Dew was anciently thought to possess wonderful properties. Baths in this precious liquid were said greatly to conduce to beauty. It was collected for this purpose, and for the use of the alchemists in their weird experiments, by spreading fleeces of wool upon the ground. Laurens, a philosopher of the middle ages, claimed that dew is ethereal, so that if we should fill a lark's egg with it and lay it out in the sun, immediately on the rising of that luminary, the egg would fly off into the air!

Fogs. Fogs are formed when the temperature of the air falls below the dew-point, *i. e.*, the temperature at which dew is deposited for a given degree of humidity. They are characteristic of low lands, rivers, etc., where the air is saturated with moisture.

Clouds. Clouds differ from fogs only in their elevation in the atmosphere. They are produced chiefly by the cooling due to expansion as currents of warm moist air rise high above the surface of the ground. In tropical regions they float only at great heights; in arctic regions, near the ground.

The stratus cloud is composed of broad, widely-extended cloud-belts, sometimes spread over the whole sky. It is the lowest cloud, and often rests on the earth, where it forms a fog. It is the night-cloud.

The cumulus cloud is made up of large cloud-masses looking like snow-capped mountains. It forms the summits of pillars of vapor, which, streaming up from the earth, are condensed

FIG. 228.

Different kinds of Clouds—one bird indicates the Nimbus, two birds the Stratus, three birds the Cumulus, and four birds the Cirrus cloud.

in the upper air. It is the day-cloud. When of small size and seen near midday, it is a sign of fair weather.

The cirrus (curl) cloud consists of light, fleecy clouds floating high in air. It is composed of little needles of ice or flakes of snow.

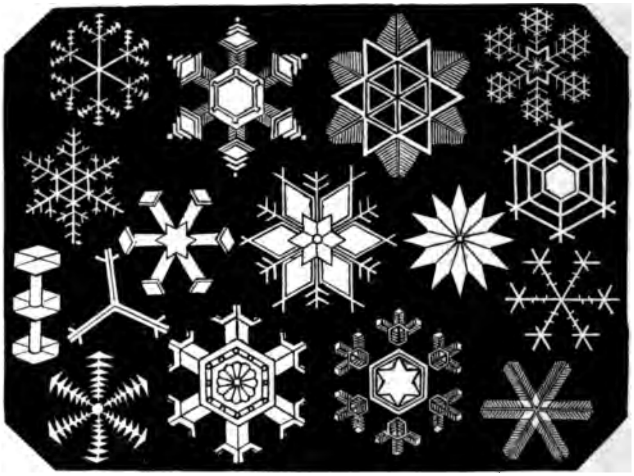
The cirro-cumulus is formed by small rounded portions of cirrus cloud, having a clear sky between. Sailors call this a "mackerel sky." It accompanies warm, dry weather.

The cirro-stratus is produced when the cirrus cloud spreads *into long, slender strata.* It forebodes rain or snow.

The cumulo-stratus is due to increase in thickness of the cumulus clouds, becoming denser and darker below, while the upper parts flatten out and thus appear like the stratus clouds. They often precede thunder-storms.

The nimbus cloud is that from which rain falls. It may be produced by the thickening of any of the forms just described.

FIG. 220.



Snow-crystals.

Rain. Rain is the product of rapid condensation of vapor in the upper regions. At a low temperature the vapor is frozen directly into snow. This may melt before it reaches the earth, and fall as rain or sleet. A sudden draught of cold air into a heated ball-room has produced a miniature snow-storm. The wonderful variety and beauty of snow-crystals are illustrated in the figure.

Rain always warms the air. Vapor can not condense without giving out as temperature the energy which had kept its molecules apart in the vaporous state.

A gallon of water weighs ten pounds, and if spread out so as to form a layer an inch thick, it would cover about two square feet of space. To cover a square mile an inch in depth,

FIG. 230.

Sea-breeze.

60,000 tons of rain are required, or 12,000,000 gallons. In the condensation of the vapor needed to produce a single gallon,

FIG. 231.

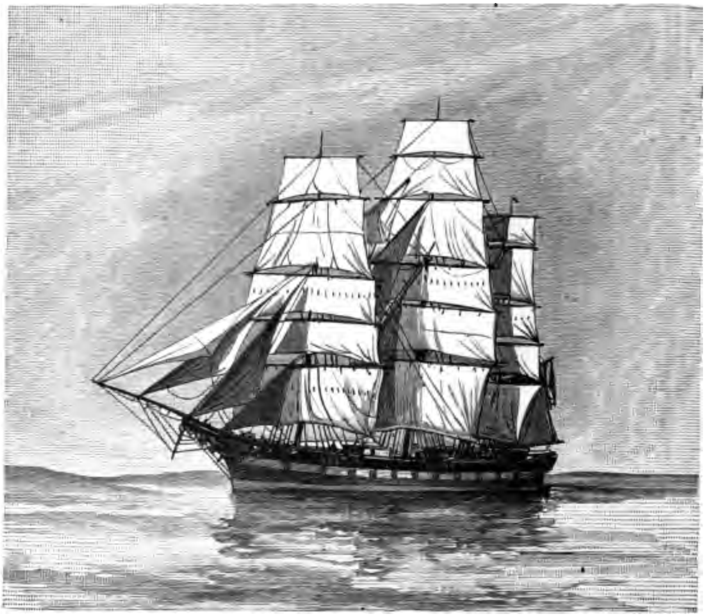
Land-breeze.

heat enough is given out to melt 75 pounds of ice, or to make 45 pounds of cast-iron white-hot. Hence an inch of rain-fall on *each square mile implies* an evolution of heat sufficient to melt

a layer of ice spread over the ground 8 inches thick, or to liquefy a globe of iron 130 feet in diameter, or a rod of it a foot in thickness and 260 miles in length.

It has been estimated that the heat given to the west coast of Ireland by rain-fall is equivalent to half of that derived from the sun. At Cherrapoonjee, in India, the annual rain-fall is four times as great as on the coast of Ireland.

FIG. 232.



Ship in the Trade-winds.

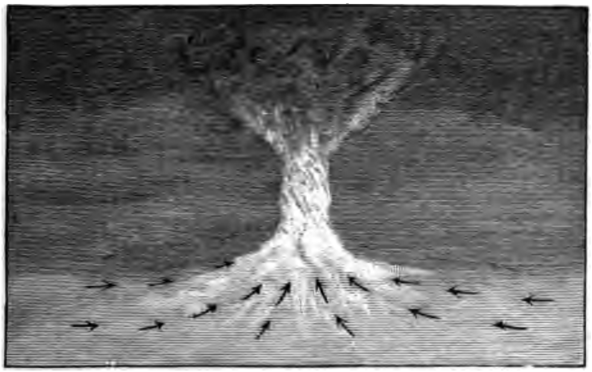
Winds. Winds are produced by variations in the temperature of the air. The atmosphere at some point is heated and expanded; it rises and colder air flows in to supply its place. This produces currents. The land and sea breezes of tropical islands are caused by the unequal specific heat of land and water. During the day the land becomes more highly heated than the water, and hence *toward noon* a sea-breeze sets in from the ocean, and is strong-

est in the afternoon. At night the land cools faster than the water, and so a land-breeze sets out from the land, and is strongest after midnight.

Trade-winds are so named because by their regularity they favor commerce. A vessel on the Atlantic Ocean will sometimes, without shifting a sail, set steadily before this wind from Cape Verde to the American coast.

The air about the equator is highly heated, and, rising to the upper regions, flows off north and south. The cold air near the poles sets toward the equator to fill its place. If the earth were at rest, this would make an upper current flowing from

FIG. 233.



Formation of Whirlwinds

the equator, and a lower current flowing toward it. As the earth is rotating on its axis from west to east, the under current starting from the poles is constantly coming to a part moving faster than itself. It therefore lags behind. When it reaches the north equatorial regions, it lags so much that it becomes a current from the north-east, and in the south equatorial regions a current from the south-east.

Whirlwinds are most frequent in the morning, when the air is at rest, and never occur when a breeze is blowing.

Whirlwinds.

The lower layer of air has been warmed by the hot *earth until it* has a temperature of perhaps *90° F. The* upper layer at a distance of 3,000 feet

more is scarcely 75° F., being 1° cooler for every 183 feet. This position of the two layers of air is a very unstable one, because the air next the earth is much lighter than that above it.

By and by, some slight disturbance starts a slender column of air upward. Immediately, the pressure of cold air forces the warm air upward through the opening. The warmer air, pressed toward the channel up which it passes, moves with

FIG. 234.

Ship Overtaken by a Cyclone.

enough force to carry a cloud of dust and fine sand. This is carried upward until it ascends hundreds of feet into the air. As the air from the surface blows from all directions toward the rising column, the latter soon begins a whirling motion. The upward rush, as well as the whirl, increases in velocity, until the warm air has ascended, and the colder layer has sunk to the ground.

On deserts and arid plains, these whirls begin as soon as *the sun is two* or three hours above the horizon. Sometimes,

several of them may be seen rising as slender columns, each several hundred feet in height. During the morning, a gentle wind sets in, which, by mixing the warm with the cold air, prevents their further formation.

The whirlwinds of the desert differ from the cyclones of the Indian Ocean, the hurricanes of the West Indies, and the typhoons of the China Sea, in violence only.

FIG. 235.

Water-spouts.

Water-spouts.

Water-spouts are caused in the same manner as whirlwinds. The whirl that makes a water-spout must have sufficient velocity to form a vacuum at its center. Into this center the water is drawn—or rather forced. It rises a few feet as a solid column, and then breaks into a dense cloud of spray and vapor.

Ocean currents are produced in a similar manner. The *water heated by the* vertical sun of the tropics rises and flows

toward the poles. The Gulf Stream carries the heat of the Caribbean Sea across the Northern Atlantic to the shores of Scotland and Norway. This great stream of warm water, flowing steadily through the cold water of the ocean, rescues England from the snows of Labrador. Were it not for the barrier of a chain of mountains connecting North and South America, Great Britain would be condemned to arctic glaciers.

Ocean Currents.

Adaptations of Water.

The great specific heat of water exercises a marked influence on climate. It tends to prevent sudden changes of weather. In the summer, it absorbs vast quantities of heat, which it gives off in the fall, and thus moderates the approach of winter. In the spring, the melting ice and snow drink in the warmth of the sunbeam. Since so much heat is required to melt the ice and snow, they dissolve very slowly, and thus ward off the disastrous floods which would follow, if they passed quickly into the liquid state.

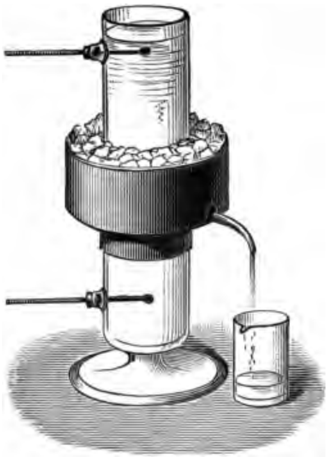
Water contains air, which is necessary for the support of animal life. This air not only makes it available as a home for fish and other creatures that inhabit the water, but also makes the change from water to steam more gradual. Much of it is driven off when the water is heated. When water has been carefully deprived of the air usually held in solution, it is liable to violent commotion at any moment when it is heated above 212° F. With such water, every stove-boiler would need a thermometer. A tea-kettle would require as careful watching as a steam-engine, and our kitchens would witness frequent and perhaps disastrous explosions.

Water, like other liquids, expands with heat and contracts, on cooling, down to 39° F. At this temperature, it has its greatest density. On cooling it further, there is slight expansion until 32° F. is reached, when it rapidly expands about one tenth in freezing. This expansion is due to the formation of crystals. These, on account of their angular form, require more space than liquids do. It is thought that between 39° and 32° crystallization is going on among the molecules. As soon as a few crystals are definitely formed, each serves as a nucleus around which others gather, and the process becomes then far more rapid.

Since ice when it melts contracts, pressure aids in liquefaction and so lowers the melting-point. In descending over the rough surface of a mountain slope, glacier ice is subjected to alternate pressure and extension. The pressure melts it and makes the mass slide farther down. Passing over some ledge, it snaps, producing great fissures. When the walls of these come into contact they freeze together again, but only to be remelted.

Certain metals, such as bismuth and iron, act like water in this respect, and are hence well fitted for making sharp castings, filling every crevice of the mold as they expand in crystallizing.

Fig. 236.



Testing the Density of Water.

Fit a small flask with a cork, through which passes an upright glass tube. Fill with colored water. Apply heat to the flask until the liquid runs over the top of the tube. This shows the expansion by heat. Now apply a freezing mixture to the flask, and at first the liquid in the tube falls, but soon begins to rise. When it runs over as before, apply heat and it shrinks back again. Thus cold will expand and heat contract it. When water is at its maximum density (about 39°) expansion sets in alike, whether you heat or cool it.

The maximum density of water can be determined by the following method. We have represented in Fig 236 a glass jar having two lateral openings, one near the top, and the other near the bottom. Into these apertures are inserted two thermometers. The jar is filled with water, and a freezing mixture placed around its central part. If the freezing mixture remains long enough about the jar, we shall have the following results.

The lower thermometer falls to 4° C., or 39.2° F., and *remains at that point.* The upper one at first changes very little,

but when it reaches the fixed temperature, it begins to fall until it sinks to the freezing-point, when the water at the surface freezes. The reason is this: as the water in the center grows colder its density increases, and it falls to the bottom. This process goes on until all the water in the lower part of the vessel has reached the temperature of 39.2° F.

When this portion of the water has this temperature, circulation in it ceases, until needles of ice are formed, which, being lighter, rise to the surface and start up a new circulation, which causes the water to freeze at the surface, while that near the bottom remains at 39.2°.

This experiment proves that water is heavier at 39.2° than at 32°, since it sinks to the lower part of the vessel.

The crystallization of water is of great importance in connection with the freezing of our lakes and rivers. Were it not crystalline when frozen, the water at the surface during severe weather, radiating its heat and becoming chilled, would contract and fall to the bottom, while the warm water below would rise to the top. This process would continue until the freezing-point was reached, when the whole mass would solidify into ice. Our lakes and rivers would freeze solid every winter.

This would be fatal to all animal life in the water, at least of the higher orders, such as fish. In the spring, the ice would not, as now, buoyant and light, float and melt in the direct sunbeam, but, lying at the bottom, would be protected by the non-conducting water above. The longest summer would not be sufficient to thaw the deeper bodies of water. As it is, the ice is formed at the surface, and there it floats, protecting the water beneath from further reduction of temperature.

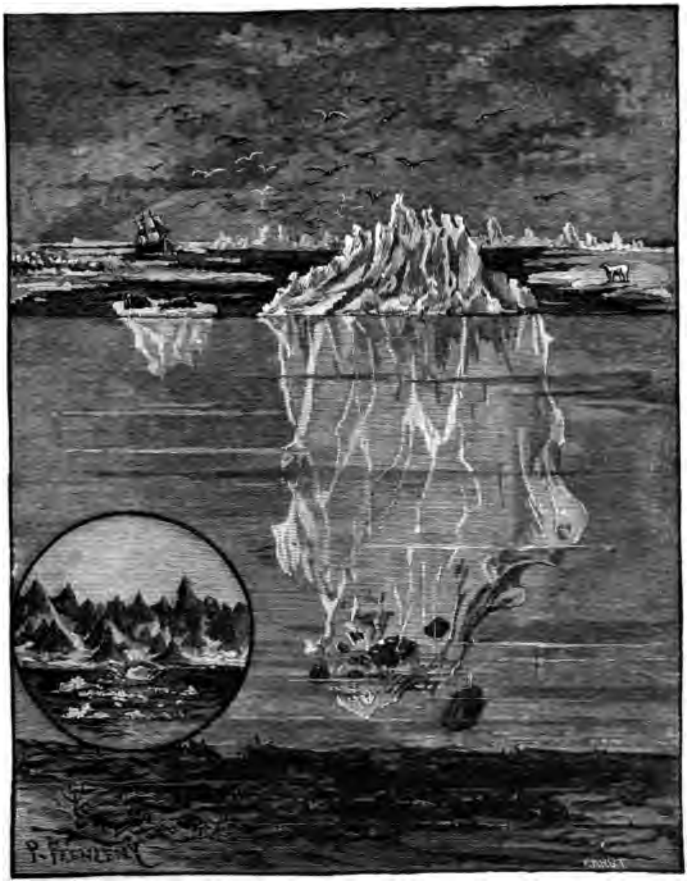
This is well illustrated in the accompanying cut of an iceberg, and an ice-floe, Fig. 237. Since from an eighth to a tenth of the mass of ice is above water, it soon melts away after drifting into warmer latitudes, or being exposed to the sunshine of summer.

Icebergs.

Water, in freezing, has a tendency to free itself from salts and other substances dissolved in it. Thus, melting ice furnishes a means of obtaining fresh water in Arctic regions. If a barrel of vinegar freeze, we shall find much of the acid collected in a mass about the center of the ice.

Water distills from the ocean and land as vapor, at one time cooling and refreshing the air, at another moderating its wintry

Fig. 237.



Iceberg and Ice-floe.

rigor. It condenses into clouds, which shield the earth from the direct rays of the sun, and protect against excessive radiation. *It falls as rain, cleansing* the air and quickening vegetation wit

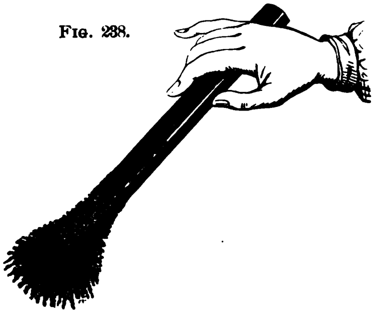
renewed life. It descends as snow, and, like a coverlet, wraps the grass and tender buds in its protecting embrace. It bubbles up in springs, invigorating us with cooling, healing draughts in the sickly heat of summer. It purifies our system, dissolves our food, and keeps our joints supple. It flows to the ocean, fertilizing the soil, and floating the products of industry and toil to the markets of the world.

CHAPTER IX.

MAGNETISM.

"NEXT in order I will proceed to discuss by what law of Nature it comes to pass that iron can be attracted by that stone which the Greeks call the Magnet, from the name of its native place, because it often produces a chain of [iron] rings hanging down from it. Thus you may see five and more suspended in succession and tossing about in the light airs, one always hanging from the other and attached to its lower side, and each in turn, one from the other, experiencing the binding power of the stone; with such a continued current, its force flies through all."

FIG. 238.



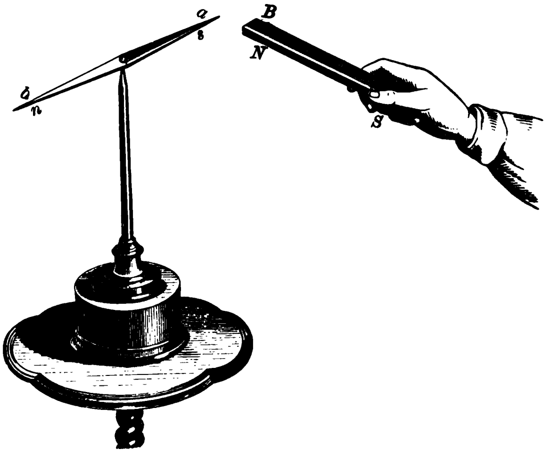
Magnet Dipped in Iron Filings.

MAGNETS *probably* became first known to European nations *through the discovery* of natural magnets by the Greeks in

the Thessalian district of Magnesia. From this the name was taken. A natural magnet is an ore of iron generally known as lodestone, which has the power of attracting iron, and a few other elements, such as nickel and cobalt. They are all called magnetic bodies, but for ordinary purposes iron may be regarded as the only one of importance. The artificial magnet is a steel bar that has acquired properties like those of lodestone. If it be straight, it is called a bar magnet; if U-shaped, a horseshoe

Magnets.

FIG. 239.



Influence of one Magnet on another.

magnet. A piece of soft iron called the armature is placed so as to connect the two ends of the horseshoe.

If we insert a magnet in iron filings, they will cling chiefly to its ends termed the poles. The magnetic force will be exerted even through any intervening body that is not itself magnetic.

If a slender bar magnet be suspended or pivoted properly, so as to swing freely in a horizontal position, one pole will point toward the neighborhood of the north and the other in the opposite direction. The former is called the north, or positive (+) pole, and

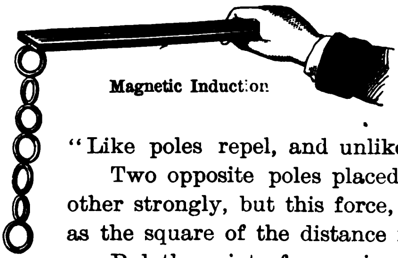
The Magnetic Meridian.

the latter the south, or negative (—) pole. A magnet thus poised constitutes a magnetic needle.

Laws of Magnetism.

If a magnet is held near a magnetic needle, the south pole of one attracts the north pole, and repels the south pole of the other. This is a sufficient proof of the law—"Like poles repel, and unlike poles attract."

FIG. 240.



Magnetic Induction

Two opposite poles placed near together attract each other strongly, but this force, like gravitation, diminishes as the square of the distance increases.

Rub the point of a sewing-needle across the north pole of a magnet. Bring the point near the south pole of the magnetic needle. The needle will be repelled, showing that the point of the sewing-needle has become a south pole. Suspend a key from the north pole of a magnet. Bring the south pole of an equal magnet close to the upper end of the key. The key will instantly fall. Suspend a long iron wire from the north pole of a magnet. Bring the north pole of the second magnet near the lower end of the wire. The wire is repelled, because its lower extremity possesses north polarity. Immerse the unlike poles of two magnets in iron filings. Bring the two poles near each other. The filings will move toward one another. But if the poles of the magnets are like, the filings will fall off the magnets. To ascertain whether a metallic substance contains iron: Bring the substance near one of the extremities of a magnetic needle. If the position of the needle be affected, then the substance almost certainly contains iron. A piece of copper will not affect the magnetic needle.

Induction.

Induction is the process of developing magnetism by bringing a magnetic body and a magnet near together. If a piece of soft iron be brought near a magnet, it immediately assumes the magnetic state, but loses it on being removed. In steel, the change is induced and lost much more slowly. The end of the bar next to the south *pole of the magnet* becomes the north pole of the new magnet *and vice versa.* When opposite states are thus developed in th

opposite ends of a body, it is said to be polarized. Whenever an object is attracted by a magnet, it is supposed first to be made a magnet (polarized) by induction, and then the attraction consists in that of unlike poles for each other. Thus we may suspend from a magnet a chain of rings held together by magnetic attraction. Each link is a magnet with its north and south poles. Each particle of the tuft of filings in Fig. 238 is a distinct magnet. By inducing magnetism, a magnet does not lose force. It rather gains by the reciprocal influence of the new magnet. An armature acts in this manner to strengthen a magnet. Instead of rings, iron keys, nails, or bits of wire, of varying length, may be used.

FIG. 241.

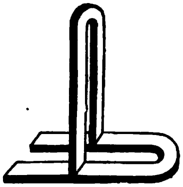
Polarization of an Iron Bar.

If we break a magnet, the smallest fragment will have a north and a south pole. This is explained by supposing that every molecule contains two opposite kinds of energy which neutralize each other. When the bar is magnetized these are separated, but do not leave the molecule. This is hence polarized, the halves assuming opposite magnetic states, as shown in Fig. 241. The light half of each little circle represents the positive, and the dark the negative side. All the molecules exert their negative force in one direction, and their positive in the other. The forces thus neutralize each other at the center, but manifest themselves at the ends of the magnet. Hence it is impossible to produce a magnet with only one pole. Each pole necessitates the presence of the other.

How to Make a Magnet.

Place the inducing magnet, as shown in Fig. 242, on the unmagnetized bar (which any blacksmith can make from a bar of steel), and draw it from one end to the other several times, always carrying it back through the air to the starting-point.

FIG. 242.

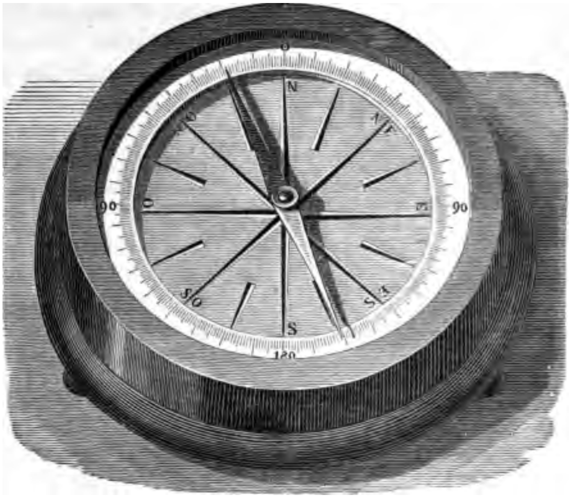


Making a Magnet.

A needle may be magnetized by laying it across the poles of a horseshoe magnet. After remaining a few hours, the end in *contact with* the north pole of the magnet *will become* a south pole and the other a north pole. If it be

suspended from the middle by a thread, it will point north and south. A knife-blade may be magnetized by rubbing it several times, in the same direction, across one of the poles of the magnet.

FIG. 243



The Compass.

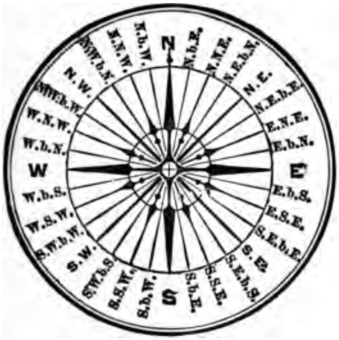
The Compass.

The compass is a magnetic needle used by mariners, surveyors, etc. It is delicately poised over a card on which the "points of the compass" are marked. At most places, the needle does not point directly N. and S. The "line of no variation" in the United States passes near Wilmington, N. C., Charlottesville, Va., and Pittsburg, Pa. East of this, the declination of the needle from true north is toward the west, and west of it the declination is toward the east.

The tendency of a magnetized needle to point in a definite direction was early noticed, and it is thought that the compass was invented by the Chinese. The first mention of the use of the magnetic needle in Europe occurs in 1190. The needle was floated on a cork, and in this way it served as a guide to the *Chinese travelers.* By the end of the fifteenth century, the

compass was known to most European sailors, and its use was specially frequent among the Spanish and Portuguese. The declination of the needle was known to the Chinese in the beginning of the twelfth century. Columbus discovered it independently in 1482, just ten years before his discovery of America. The first known work for the use of seamen was written during the reign of Queen Elizabeth. It was entitled "A Discourse on the Variation of the Cumpas or Magneticall Needle," and is dedicated to "the travaillers, sea-men, and mariners of England."

FIG. 244.



Directions.—North,—East, etc.

FIG. 245.

Magnetic Curves.

Lines of Force. The region in the neighborhood of a magnet pole within which it can have a perceptible effect upon magnetic bodies is called its field. The directions which these bodies tend to assume are *called lines of force*. Over a bar magnet lay a sheet of paper *or a plate of glass*, and sprinkle fine iron filings over this. On

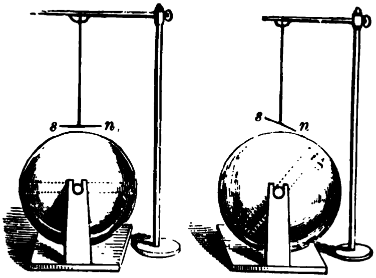
gently tapping the plate they become arranged in curved lines, many of which seem to radiate from the poles. These are the indicators of the lines of force, the position of each iron filing being determined by its direction and distance from the two poles of the magnet.

Between the two opposite poles of a horseshoe magnet, or of two separate magnets brought near together, the lines of force are straight.

Polarity of the Needle.

The earth is a great magnet, whose opposite poles produce lines of force that permeate its body and the space around. A needle when magnetized tends to assume the direction of the line of force that passes through it. The position of the terrestrial magnetic poles is not constant, and hence the needle changes its direction accordingly.

FIG. 246. FIG. 247.



Magnet in Globe.

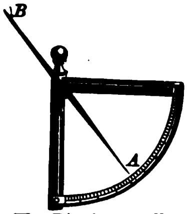
Suppose a magnet *NS* passing through the center of a small globe. The needle *sn* will hang parallel to it (Fig. 246), its positive pole being attracted by the negative pole of the magnet, and vice versa. If the globe be revolved (Fig. 247), the positive pole of the needle will turn—*dip*, as it is termed—downward. If the globe be revolved in the other direction, the negative pole of the needle will dip in the same manner.

Similar phenomena are noticed in the compass. At the magnetic equator it is horizontal, but dips whenever taken north or south. An unmagnetized needle, if poised, in our latitude, on being magnetized, settles down, as if the north end were the heavier. This is remedied by making the north end of the needle lighter, or by attaching a little weight upon the south end. The reverse is true in the southern hemisphere.

A dipping-needle is poised as shown in Fig. 248. At the magnetic *equator it hangs* horizontally, but when carried north *its positive end dips* downward more and more until it points

vertically downward at a point in Boothia Peninsula, north of Hudson Bay, called the pole of verticity, or often simply the magnetic pole. This is the negative pole of the earth. The position of its positive pole has been calculated to be beneath the Antarctic Ocean.

FIG. 248.



The Dipping-needle.

The dip was discovered accidentally in 1576 by Robert Norman, an English instrument-maker. He found the dip at London to be 71° 50′.

The declination and dip of the magnetic needle have daily and yearly variation, and also very slow changes requiring centuries to complete. In 1686, at New York, the declination was 9° west; in 1750, 6° 20′ west; in 1790, 4° 15′ west; in 1847, 6° 30′ west; in 1885, 8° west. The line of no variation was becoming slowly shifted eastward from 1686 to 1790, then became stationary, and has since been moving westward. The intensity of terrestrial magnetism at any given place has also daily variations, growing stronger by day and weaker by night.

Magnetism of the Earth.

All iron bars standing vertically (in this latitude not far from the line of the dip) possess slight magnetic properties. Iron fences, lightning-rods, iron standards of chairs and desks, pokers, tongs, crow-bars, etc., on being tested by the magnetic needle, will be found to possess positive polarity in the end next the ground, and negative polarity in the other.

Dr. Gilbert, the physician of Queen Elizabeth, published his great work, "De Magnete," about 1600. In this he announces his belief that the earth is a great magnet, controlling the direction of the needle. The variation in intensity of the earth's magnetic force has become known chiefly during the present century.

The cause of the earth's magnetism and of the variations in it is not yet known.

CHAPTER X.

ELECTRICITY.

"THAT power which, like a potent spirit, guides
The sea-wide wanderers over distant tides,
Inspiring confidence where'er they roam,
By indicating still the pathway home;—
Through Nature, quickened by the solar beam,
Invests each atom with a force supreme,
Directs the cavern'd crystal in its birth,
And frames the mightiest mountains of the earth;
Each leaf and flower by its strong law restrains,
And binds the monarch Man within its mystic chains."
HUNT.

ONE'S hair often crackles under a gutta-percha comb. Stroke a cat's back in a dark, dry room; the crackling will be heard and little sparks will be seen. In cold, frosty weather, a person, by shuffling about in his stocking-feet upon the carpet, can develop so much electricity in his body that he can ignite a jet of gas by simply applying his finger to it. Blasts in mines intended to be fired by electricity have thus been prematurely discharged by the workmen touching the wires. To prevent this disastrous effect, at the Sutro Tunnel, Nevada City, the workmen who are handling exploders wet their boots, stand on an iron plate to conduct off the electricity of the body, and wear rubber gloves. Thales (6th century B. C.), one of the seven wise men, knew that when amber is rubbed with silk it will attract light bodies, as straw, leaves, etc. This property was considered so marvelous that amber was supposed to possess a soul. From the Greek name of the substance (elektron) our word electricity is derived. This simple phenomenon constituted all that was known until the 16th century, when William Gilbert, physician to Queen Elizabeth, made many valuable experiments. He discovered that amber was by no means the only

substance which can exhibit electrical manifestations when rubbed, and he examined into the conditions favorable to electrical phenomena. Of these he found the dryness of the atmosphere to be among the most important.

Touch together the two wires of a common battery-cell and then separate them; a minute snap will be heard and a spark seen. The same may be noticed when a small dynamo in motion is substituted for the battery. A magnetic needle quickly shows that the dynamo is in the midst of a field of magnetic force.

The effects observed are due to electricity. We do not know with certainty what is its nature, but we recognize it by its effects. According to the mode of production and the nature of the effects, the discussion of it may be conveniently divided.

Frictional electricity is the name given to that obtained directly or indirectly by friction, as with the cat's back. Voltaic electricity is that produced from a battery. Electricity may be transformed into various other modes of energy.

FRICTIONAL ELECTRICITY.

Electricity.

Electricity may be developed by friction. There are more delicate modes of detecting it than those just described. Any instrument adapted to this purpose is called an electroscope.

The Electroscope.

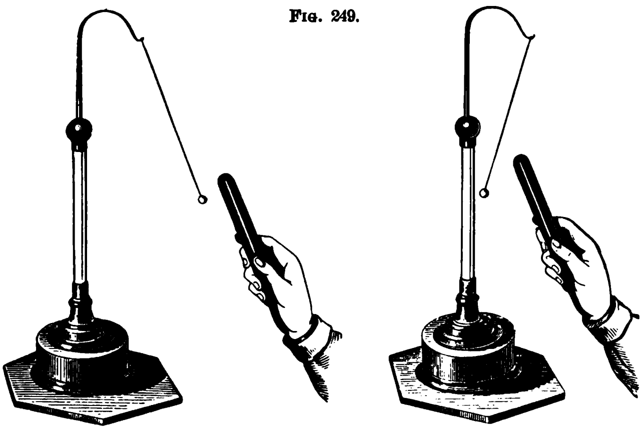
Bend a glass tube and suspend from it by silk threads an elder-pith ball, as shown in Fig. 249; or put an egg in a wine-glass, and balance on the egg a dry lath. Each may serve as an electroscope. A very convenient one is a straw suspended at the middle by a silk thread so as to hang horizontally.

Electrical Attraction and Repulsion.

If a warm dry glass, such as a lamp-chimney, be rubbed with a silk handkerchief, a crackling sound will be heard. If the tube be held near the face, a sensation like that of touching cobwebs will be felt. The tube will attract bits of paper, straw, feathers, etc. Present it to the pith ball of an electroscope. This will be attracted till it touches, and then fly off. The end of the suspended straw will likewise be first attracted, but then repelled just after it is touched. Grasp the pith ball or straw

for a moment. It will no longer be repelled. Rub a stick of sealing-wax with a woolen cloth or some fur. The behavior of the pith ball or straw toward it will be the same as toward the glass. But bring the rubbed sealing-wax near to the pith ball or straw that is repelled by the rubbed glass; there will be attraction instead of repulsion. If the excited glass be held on one side of a ball and the excited wax on the other, it will fly between the two, touching each in succession alternately.

Fig. 249.



Electroscopes.

From this we conclude that there are two kinds of manifestation of frictional electricity; and like kinds are manifested by repulsion, and unlike by attraction. The electricity from the glass is termed positive [+], and that from the wax, negative [—].

Dufay discovered by a series of experiments that there are two manifestations of electricity, which he called vitreous and resinous. He considered that both of these varieties of electricity possessed qualities that entitled them to be classed as fluids. Kinnersley, the friend and associate of Franklin, recognized that these two electricities were nothing else than what Franklin had already called positive and negative charges. In the following list, each substance becomes positively electrifie

when rubbed with the body following it; but negatively, with the one preceding it.—GANOT.

1. Cat's fur.	5. Cotton.	9. Shellac.	13. Caoutchouc.
2. Flannel.	6. Silk.	10. Resin.	14. Gutta-percha.
3. Ivory.	7. The hand.	11. The metals.	15. Gun-cotton.
4. Glass.	8. Wood.	12. Sulphur.	

The following simple experiments are instructive: A rubber comb passed a few times through the hair will furnish enough electricity to turn the lath entirely around, and empty egg-shells, paper hoops, etc., will follow the comb over the table in the liveliest way. Take a thin sheet of gutta-percha, about a foot square; lay it upon the table, and rub it briskly a few times with an old fur cuff; the gutta-percha will become powerfully electrified. Lift the gutta-percha by one corner, and some force will be required to separate it from the table. Hold the electrified gutta-percha in the left hand; bring the fingers of the right near the paper; it will be attracted to the hand, and sparks will pass to the fingers with a snapping sound. Hold some feathers, suspended by a silk thread, near the excited gutta-percha, and the feathers will be attracted. Hold the excited paper, or the excited sheet of gutta-percha, over the head of a person with dry hair; the hair will be attracted by the gutta-percha, and each particular hair will stand on end. Hold the excited gutta-percha near the wall; the gutta-percha will fly to it, and remain some minutes without falling. Place a sheet of gutta-percha on a tea-tray; rub the gutta-percha briskly with a fur cuff; place the tea-tray with the excited sheet of gutta-percha on a dry tumbler; lift off the gutta-percha from the tea-tray; bring the knuckle of your hand near the tray, and you will receive a spark. Replace the gutta-percha on the tray and apply your knuckle, and you will receive another spark. This may be repeated a dozen times. Take a sheet of foolscap paper and a board about the same size. Heat both till they are thoroughly dry. While hot, lay the paper on the board and rub the former briskly with a piece of rubber. The paper and board will cling together. Tear the paper loose and try the gutta-percha experiments with it. Return the paper and rub as before. Cut the paper so as to form a tassel. Then

lift, and the strips of the tassel will repel one another. Take a piece of common brown paper, about the size of an octavo book, hold it before the fire till quite dry and hot, then draw it briskly under the arm several times, so as to rub it on both sides at once by the coat. The paper will be found so powerfully electrical, that if placed against a wainscoted or papered wall of a room, it will remain there for some minutes without falling. While the paper still clings to the wall hold against it a light, fleecy feather, and it will be attracted to the paper in the same way the paper is to the wall. If the paper be warmed, drawn under the arm as before, and then hung up by a thread attached to one corner, it will sustain several feathers on each side; should these fall off from different sides at the same time, they will cling together very strongly; and if, after a minute, they are all shaken off, they will fly to one another in a singular manner. Warm and excite the paper as before, and then lay on it a ball of elder-pitch, about the size of a pea; the ball will immediately roll across the paper, and if a needle be pointed toward it, it will again roll to another part, and so on for a considerable time. Support a pane of glass, well dried and warmed, upon two books, one at each end, and place some bran underneath; then rub the upper side of the glass with a silk handkerchief, or a piece of flannel, and the bran will dance up and down like the images in Fig. 256. Place a common tea-tray on a dry, clean tumbler. Then take a sheet of foolscap writing-paper, and dry it carefully until all its hygrometric moisture is expelled. Holding one end of the sheet on a table with the finger and thumb, rub the paper with a large piece of India rubber a dozen times vigorously from left to right, beginning at the top. Now take up the sheet by two of the corners and bring it over the tray, and it will fall like a stone. This forms a simple electrophorus, fit to perform many experiments ordinarily performed with that instrument. If the tip of a finger be held close to the bottom of the tray, a sensible shock will be felt. Next, lay a needle on the tray with its point projecting outward, remove the paper, and, in the dark, a star sign of the negative electricity will be seen; return the paper, and the positive brush will appear. Lay a dry, hot board on top of four tumblers. If a boy stand on the board he will b

insulated, and on his holding the tray vertically, the paper will not fall. Sparks may then be drawn from his body, and his hair will be electrified. Warm a lamp-chimney, rub it with a hot flannel, and then bring a downy feather near it. On the first moment of contact, the feather will adhere to the glass, but soon after will fly rapidly away, and you may drive it about the room by holding the glass between it and the surrounding objects; should it, however, come in contact with any thing not under the influence of electricity, it will instantly fly back to the glass.

Theory of Electricity.

It is thought that positive and negative electricity exist in every body, in a state of total or partial equilibrium. When this equilibrium is disturbed, as by friction, electrical separation follows, and each kind of electricity becomes manifested, in the same manner as in the polarization of a magnet, if the proper conditions are observed. Electricity is not a fluid, as was long taught. It may be a condition of strain among the molecules of a body, capable of being communicated like a fluid. We know only its laws, and not its nature.

Electric Potential.

A body electrically excited by friction or otherwise is said to be charged. The charge may be either positive or negative, strong or weak. If two bodies equally and oppositely charged are put into contact, the charge of each is neutralized by that of the other. A body strongly charged positively is said to be at high potential; if negatively, at low potential; when discharged, at zero potential. The surface of the earth is electrically at zero.

Conductors and Insulators.

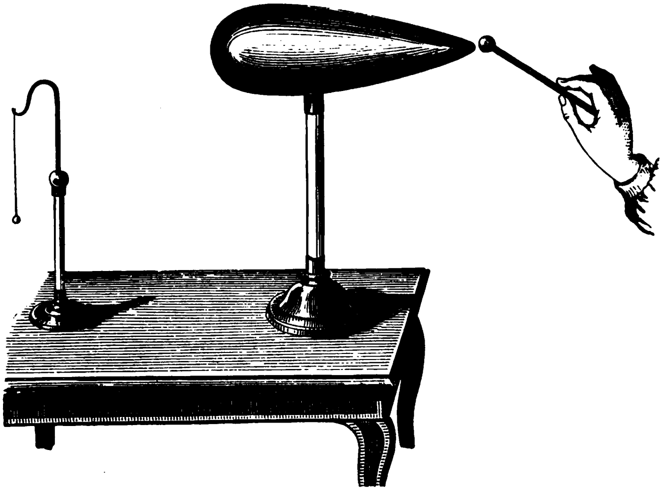
A body which allows electricity to pass through it freely is termed a conductor; one which does not, is called a non-conductor, or insulator. Stephen Gray, in the 18th century, discovered the difference between conductors and non-conductors. Copper is one of the best conductors, and hence it is used in many electrical experiments. Glass is one of the best insulators. A body is said to be insulated when it is supported by some non-conducting substance, usually glass or vulcanite. A body can be highly *charged only* when insulated. In damp air, electricity is quickly *dissipated*. This is due to the deposit, on the glass insulators,

of a thin film of moisture, which conducts away the electricity. For success in electrical experiments, therefore, it is important to keep the air dry and warm, since dry air is one of the best of insulators.

The following list contains the most common conductors and insulators:

Best Conductors.		Best Insulators.	
Metals.	Vegetables.	Shellac.	Air (dry or damp).
Charcoal.	Animals.	Amber.	Dry Paper.
Flame.	Linen.	Sulphur.	Caoutchouc.
Minerals.	Cotton.	Wax.	Ice.
Acids.	Dry Wood.	Glass.	Dry Wood.
Water.	Ice.	Silk.	Cotton.

FIG. 250.



Variation in Electric Density.

Distribution of Electricity on Bodies.

A charge communicated to one part of an insulator is not spread over its whole surface; but when a good conductor is charged at any point, the spread is instantaneous. It spreads, however, only on the surface, and not through the interior. Gray discovered that an electric charge is at the surface. A pith ball, if *made to touch the* outside of an electrified metal cup or hollow

ball, is strongly repelled; but on the interior there is no such effect. If the ball is spherical, the amount of electricity at all points of its surface is the same; or, we may say, that the electric density is uniform over its surface.

Faraday once made a hollow cube of wood, measuring twelve feet each way and covered with tin-foil. Insulating this, he charged it with a powerful machine until sparks darted off from every corner on the outside. Going within this little room with his most delicate electroscopes, he could not detect the least effect upon them. He made a conical bag of linen, and fastened its open end to an insulated ring. Pulling it out with a silken cord, he electrified it. The charge was manifest on the outside, zero on the inside. Reversing the pull so as to turn it inside out, the new exterior was found to be charged. A half-minute previously it had been a neutral interior. The student should try this interesting experiment, using the most delicate electroscope that he can make.

FIG. 251.

Faraday's Conical Bag.

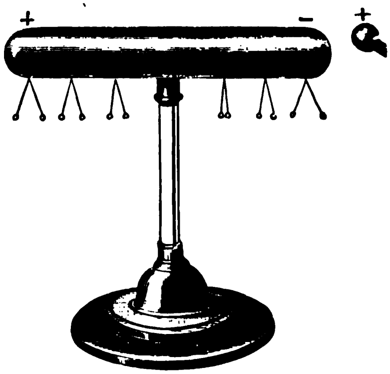
On a cylinder the electric density is greatest at the ends. If one end is blunt and the other sharp, the density at the sharp end becomes so great that the neighboring air molecules are quickly electrified by contact and instantly repelled. Others in turn are successively repelled, and the body is soon discharged. Electricity thus escapes rapidly from jutting points. The electric whirl, mounted on the prime conductor of an electrical machine, illustrates this action. As each molecule of air is repelled from a point, it reacts with equal force against the point. This is sufficient to set the light wire-wheel in rapid rotation.

Electrical Induction.

Let an insulated conductor, Fig. 252, be brought near another conductor that has been strongly charged positively, and let a series of pairs of pith balls be suspended from the first. The motion of the balls shows that the ends of the insulated conductor are elec-

trically excited, while the middle is neutral. The end nearest the charged conductor is excited negatively and the remote end positively. If the charged conductor be removed, all of the pith balls collapse. Place several insulated conductors, as shown in Fig. 252, the balls being strongly charged, that at the right positively, and that at the left negatively. Each intermediate conductor becomes excited, as indicated, and becomes neutral when the balls are discharged. It has been polarized by induction, in the same manner that a magnetic body would be when brought into the field of a magnet pole.

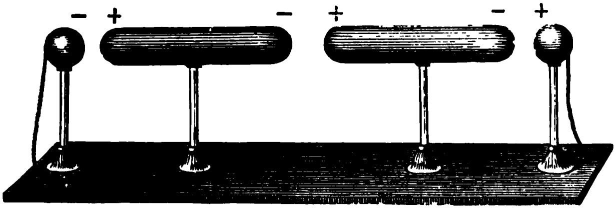
Fig. 252



Electrical Induction.

The experiment in Fig. 252 can be nicely performed by means of an egg covered with tin-foil and placed flatwise on the top of a dry wine-glass and the glass tube represented in Fig. 252. Several eggs and glasses will show the principle of Fig. 253.

Fig. 253.



Electrical Induction.

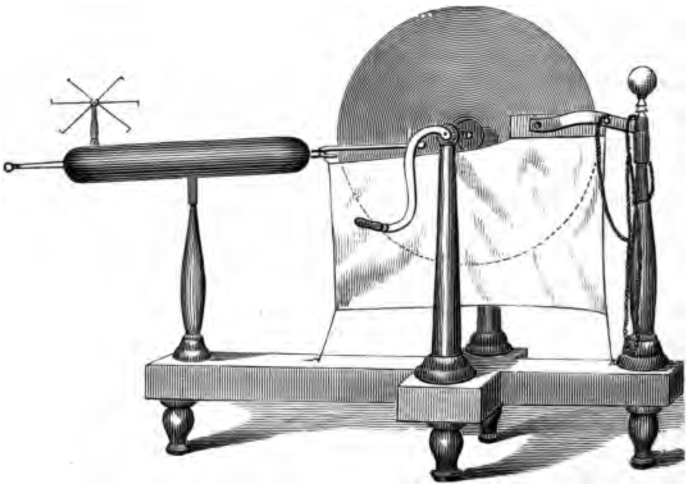
The Plate Electrical Machine.

The plate electrical machine consists of a circular glass plate, which can be turned by means of a crank; a pair of leather or cloth rubbers pressed against the plate and covered with electrical *amalgam, or tin dioxide*. Electrical amalgam is a mixture o

tin, zinc, and mercury. By experience it has been found that, when this is rubbed on glass, electrical separation is most easily effected. Tin dioxide is often called "mosaic gold," because of its metallic yellow color. It is used in bronzing.

There is also a metallic comb or fork with sharp points which nearly touch the plate; a prime conductor, consisting of a rounded brass cylinder, insulated by resting on a glass standard, and connected at one end with the comb. Frequently the

FIG. 254.



The Plate Electrical Machine.

lower half of the plate is made to revolve between a pair of silken flaps (Fig. 254). A chain is usually attached to the knob in connection with the comb, and connects this with the ground through the medium of a gas pipe or other conductor.

On turning the crank, the friction of the plate against the rubbers produces electrical separation; the rubbers becoming charged negatively, the plate positively. The negative charge is conducted off to the earth by the chain, which thus restores the rubbers to zero potential. The positive charge on the plate, when this is brought opposite the comb, polarizes the prime conductor and comb by induction. Positive electricity becomes

manifested on the remote conductor, and negative electricity at the comb is communicated at once by the sharp points to the air, whose molecules are repelled into contact with the plate, thus neutralizing its positive charge. The prime conductor is hence left charged to high potential.

The action of the plate machine is thus an application of both friction and induction.

The Theory of Attraction.

The theory of attraction is likewise an application of induction. In Fig. 249, where a glass rod at high potential is brought near a pith ball, this is polarized by induction, the nearer half becoming negative, and the remote half positive. The charge on the rod attracts the negative half and repels the positive half. But since the negative half is nearer, the attraction exceeds the repulsion, and the pith ball moves toward the rod. On touching this the negative charge is wholly neutralized, and only repulsion can be effective. Every case of electrical attraction is thus a case of induction.

The electric chime consists of three bells, two of which, *c* and *b*, are hung by brass chains, while the middle one is insulated above by a silk cord, and connected below with the earth by a chain. The balls between them are also insulated. The outer bells becoming charged with positive electricity from the prime conductor of an electrical machine, polarize the balls by induction through the intervening air. The balls being then attracted to the bells, are charged and immediately repelled. Swinging away, they strike against the middle bell, discharging their electricity, and are forthwith attracted again. Flying to and fro, they ring out a merry song.

Fig. 255.

Electric Chimes.

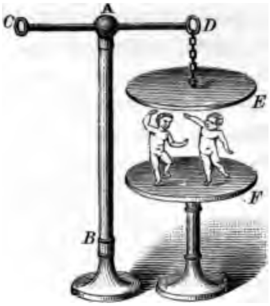
The dancing image consists of a pith-ball figure placed between two metallic plates, the upper one hanging from the prime conductor, and the lower one connected with the earth. *The dance is conducted* by alternate attraction and repulsion.

A slow motion should be given to the electrical wheel, and a pin thrust into the heel of the image will add much to the stamp of the tiny feet.

Free and Bound Electricity.

The gold-leaf electroscope is more sensitive than one of pith balls. Within a dry glass jar a pair of strips of gold-leaf are suspended from a metal rod terminating at the top in a knob or plate. If a rod, excited for example negatively, be brought near the knob, then by induction this becomes charged positively while both leaves are charged negatively, and hence repel each other. By placing the finger on the knob and withdrawing it while the rod is still near, the leaves collapse. Their negative charge has been conducted off to the earth. But on withdrawing now the rod, they diverge again and remain apart. The positive charge on the knob was "bound" there by the presence of the negatively excited rod and could not be conducted away, like the negative charge on the leaves. On removing the rod after the finger has been taken away, the positive charge becomes "free"; it is distributed over knob and leaves, and these now repel each other with a positive

FIG. 256.



Dancing Images.

FIG. 257.

Gold-leaf Electroscope.

rge. So long as a charge is "bound," it fails to manifest

itself; its energy is potential, and becomes kinetic only when freed by the removal of the inducing body.

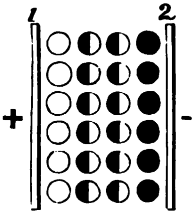
Inductive Capacity.

A body through which induction occurs is called a dielectric. Air is a good dielectric, but when two oppositely charged bodies are brought near enough together in air, each charge binding the other strongly, the intervening molecules soon attain their limit of polarization, and a spark passes, announcing that the opposite charges have become neutralized through the dielectric. Glass is a far better dielectric than air.

Electrical Condensation.

By putting a good dielectric between two conducting surfaces, one of which is connected with the prime conductor of an electrical machine and the other with the earth, electricity may be strongly "condensed" on these surfaces. In Fig. 258, let the strip on the left represent a conductor, of tin-foil, positively charged from the machine, and that on the right a similar conductor connected with the earth, the intervening space being occupied by a plate of glass. This dielectric becomes polarized, the surface on the right attaining a negative charge which is bound there, while the corresponding positive electricity on the same side is neutralized by connection with the earth. The negative charge in turn reacts through the dielectric, binding a positive charge on the left, whose energy thus becomes potential. The conductor can then receive a new charge from the machine, and the process is repeated until the greatest charge is accumulated that the condenser can carry. Its molecules are then in a condition of great strain.

Fig. 258.



The Leyden Jar.

The Leyden jar consists of a glass jar, serving as a dielectric, coated inside and outside, not quite to the top, with tin-foil. It is fitted with a cover of baked wood through which passes a metal rod with a knob at the top, and below a metal chain extending down t the inner coating. The jar is charged by bringing the knol near the prime conductor of the machine, while the outer coa ing communicates with the earth. The inner coating becom

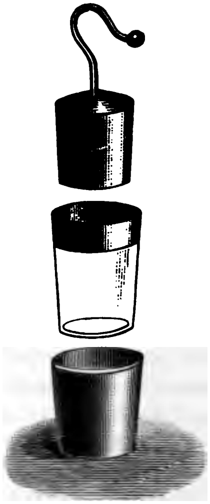
charged first from the machine, a succession of sparks being received until the two coatings acquire a large charge of bound electricity, positive within and negative without. To discharge it, one end of a conductor with an insulated handle is put on the outer coating, while the other is brought near the knob above. A sharp snap and a brilliant flash through the air announce that equilibrium is restored. Minute particles detached from the solid conductors are made momentarily white-hot, giving brilliancy to the spark. The incredibly small quantity of the metal volatized in this way is a striking proof of the divisibility of matter.

FIG. 259.

The Leyden Jar.

During some experiments at the Philadelphia mint a gold pole lost in weight by a strong spark one millionth of a grain; and $\frac{1}{8\,880\,000}$ of a grain of nickel signed its name in the spectroscope brilliantly.

FIG. 260.



Leyden Jar with Movable Coatings.

It is said that Cuneus, a pupil at Leyden, discovered the principle of the Leyden jar in the following curious way. While experimenting, he held a bottle of water to the prime conductor of his electrical machine. Holding the bottle with one hand, he happened to touch the water with the other, when he received a shock so unexpected, and so unlike any thing he had ever felt before, that he was filled with astonishment. It was two days before he recovered from his fright. A few days afterward, in a letter to a friend, the physicist innocently remarked, that he would not take another shock for the whole kingdom of France.

The tin-foil on a Leyden jar serves only as a conductor, and not as an accumulator, of the charge. The jar may be

made with movable coatings, as in Fig. 260. After it is charged these may be removed. Putting the same jar then into another set of coatings, it may be discharged in the usual manner.

The Leyden jar was invented in 1745, probably by several persons about the same time; it was first exhibited and used in experiment by Muschenbroeck, at Leyden, in Holland. By the use of it students of electricity were able to gather the mysterious "virtue" or "effluvia" in much larger quantities, and to produce effects never imagined before, such as the firing of gunpowder. Experiments were made about this time to ascertain the rate of transmission of electricity from a Leyden jar through a metallic conductor. A wire more than two miles long was employed; through this the discharge appeared to be absolutely instantaneous.

In 1749, Benjamin Franklin wrote from Philadelphia to Peter Collinson at London, as follows:

"Chagrined a little that we have hitherto been able to produce nothing in this way of use to mankind, and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure on the banks of the Skuylkil. Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water; an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by the electrical shock, and roasted by the electrical jack before a fire kindled by the electrical bottle (Leyden jar); when the healths of all the famous electricians in England, Holland, France, and Germany are to be drank in electrified bumpers, under the discharge of guns from the electrical battery."

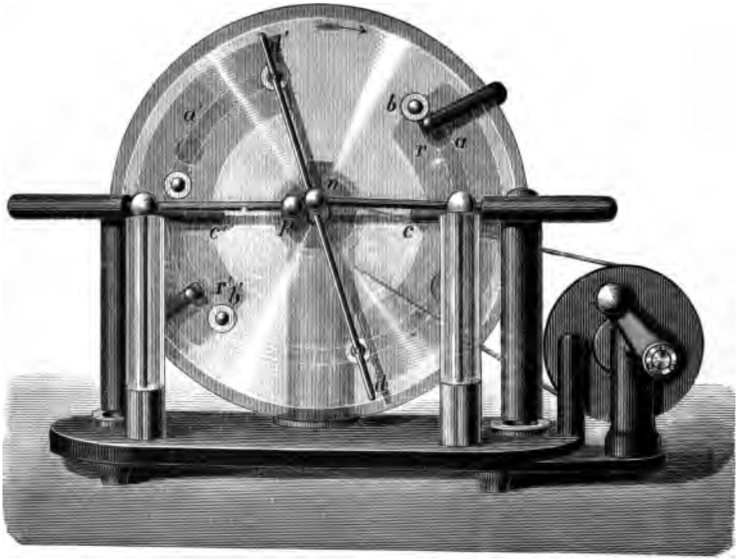
The Voss Electrical Machine.

Many improvements have been made on the plate electrical machine. One of the best is the Voss machine.* This consists of a fixed glass plate, in front of which revolves a smaller one provided with six metallic

* For a long time the best electrical machine was that devised by a German physicist, M. Holz. Two of his countrymen, Voss and Toepler have improved it greatly. The one described in the text is often called a *Toepler-Holz machine.*

buttons (Fig. 261, *b*). On the rear of the fixed plate are two sheets of varnished paper, *a* and *a'*. Each covers a strip of tin-foil, called the armature, from which a metallic arm extends around to the front, ending in a rubber of brass filaments, *r*. Under this each button passes. A pair of combs, *c* and *c'*, connect with adjustable discharging rods, *p* and *n*. Another pair of combs and rubbers are attached to the brass rod,

FIG. 261.



The Voss Machine.

dd'; this extends across in front of the plate, which revolves in the direction shown by the arrows.

If there be the least possible difference of potential between the two armatures, such as is naturally due to accidental conditions on their surfaces, it may be greatly increased by revolving the plate. Suppose the left armature, *a'*, to be faintly charged positively, while the right armature, *a*, is neutral; then *a'* induces a slight negative bound charge on the button in front, which in revolving passes under *a'*. Passing from *a'*

to r, the button comes opposite a neutral armature. Its negative bound charge at once becomes free and is conducted through the rubber r to the armature behind, charging it negatively. This at once acts inductively on the button, causing it to acquire a positive bound charge with which it passes d. This charge is freed at r' and conducted to the armature a', strengthening its positive charge. This process continues, both armatures becoming soon strongly and oppositely charged. The comb, c', by induction from a, is polarized. It discharges negative electricity, while the rod, p, acquires a strong positive charge. In like manner c discharges positive electricity and n acquires a strong negative charge. A succession of sparks soon passes between p and n, the strength of which is greatly increased by condensation in the Leyden jars, with which the discharging rods are connected.

Lightning.

Lightning is only the discharge of a Leyden jar on a grand scale. About 1752, Franklin proved the identity of lightning and frictional electricity by means of a kite made of a silk handkerchief, and with a pointed wire at the top. He elevated this during a thunder-storm, tying at the end of the hemp string a key, and then insulating the whole by fastening it to a post with a long piece of silk lace. On presenting his knuckles to the key, he obtained a spark. He afterward charged a Leyden jar, and performed other electrical experiments in this way. These attempts were attended with very great danger. Prof. Richman, of St. Petersburg, drew in this manner from the clouds a ball of blue fire as large as a man's fist, which struck him lifeless. Shortly after the famous experiments of Franklin, the Frenchman, Coulomb, established the law of electric attraction and repulsion, showing that it was the same as that of gravitation, light, and heat, the law of inverse squares. If two clouds with opposite charges of electricity come near together, the intervening air reaches its limit of polarization, and a flash occurs like that between the discharging-rods of the Voss machine. Francis Hawksbee called attention to the resemblance between the electric spark and lightning, and invented an electric machine, *in which the hands* were used as rubbers. The air is *constantly electrified.* In clear weather it is in a positive state,

but in foul weather it changes rapidly from positive to negative, and vice versa. Dr. Livingstone tells us that in South Africa the hot wind which blows over the desert is so highly electrified, that a bunch of ostrich feathers held for a few seconds against it becomes as strongly charged as if attached to an electrical machine, and will clasp the hand with a sharp, crackling sound.

The air is never quite uniform in conducting power at all places, and the immense spark, moving along the line of least resistance, describes a zigzag course. It suddenly heats the air, which expands and instantly collapses. The concussion produces a series of air-waves from successive parts of the spark. These constitute thunder, which continues to roll because the sound is reflected many times from clouds, and from masses of air which differ among themselves in density. Often the charged cloud approaches the ground rather than another cloud. Discharge takes place, and exposed objects, such as tall houses or trees, are destroyed if included in the lightning's path.

Lightning-rods were invented by Franklin. Franklin's plan was opposed by many men of his day, who declared it was as impious to ward off Heaven's lightning, "as for a child to ward off the chastening rod of its father." There was much discussion as to whether the conductors should be pointed or not. Wilson persuaded George III. that the points were a republican device to injure His Majesty, as they would certainly "invite" the lightning, and so the points on the lightning-rods upon Buckingham Palace were changed for balls.

Lightning-rods are based on the principle that electricity always seeks the best conductor. The rod should be pointed at the top with some metal which will not easily corrode. If constructed in several parts, they should be securely jointed. The lower end should extend into water, or else deep into the damp ground, beyond a possibility of any drought rendering the earth about it a non-conductor, and be packed about with ashes or charcoal. If the rod is of iron, it needs to be much larger than one of copper, which is a better conductor. Every elevated portion of the building should be protected by a separate rod. Chimneys need especial care, because of the ascending olumn of vapor and smoke. Water conductors, tin roofs, etc.,

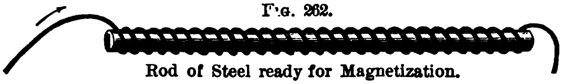
should be connected with the damp ground or the lightning-rod, that they may aid in conveying off the electricity. The value of a lightning-rod consists, most of all, in its power of quietly restoring the equilibrium between the earth and the clouds. By erecting lightning-rods, we thus lessen the liability of a sudden discharge. Every drop of rain, and every snow-flake, falls charged with electric energy, and thus quietly disarms the clouds of their terror. The balls of electric light, called by sailors "St. Elmo's fire," which sometimes cling to the masts and shrouds of vessels, and the flames said to play about the points of bayonets, indicate the quiet escape of electricity from the earth toward the clouds.

The duration of the flash from a Leyden jar has been found to vary from two thousandths to forty billionths of a second. When the plate of the Voss machine is revolving at the highest speed, each button can be momentarily seen, as if it were still, when illuminated by the spark. The trees swept by the tempest, or a train of cars in rapid motion, when seen by a flash of lightning, seem motionless; while a cannon-ball, in swift flight, appears poised in mid-air.

Effects of Frictional Electricity.

Discharges from a large battery of Leyden jars will melt metal rods, perforate glass, split wood, magnetize steel bars, etc. Let a person stand upon an insulated stool and become charged from the prime conductor. His hair, through repulsion, will stand erect in a ludicrous manner. On presenting his hand to a little ether contained in a warm spoon, a spark leaping from his extended

Fig. 262.



Rod of Steel ready for Magnetization.

finger will ignite it. If he hold in his hand an icicle, the spark will readily dart from it to the liquid. This experiment can be more surely performed by using disulphide of carbon. The insulating stool may be merely a board laid on four dry flint-glass bottles or goblets, and the electricity be developed by rubbing a glass tube. A card held between the knob of a Leyden jar and that of the discharger, will be punctured by the spark. A

piece of steel may be magnetized by the discharge from a Leyden jar. Wind a covered copper wire around a steel bar, as in Fig. 262, or inclose a needle in a small glass tube, around which the wire may be wound. On passing the spark through the wire, the needle will attract iron filings. When strips of tin-foil are pasted on glass, and figures of various patterns cut from them, the electric spark leaping from one to the other presents a beautiful appearance. If a battery be discharged through a small wire the electricity will be changed to heat, and the wire, if sufficiently small, will be fused into globules or dissipated in smoke.

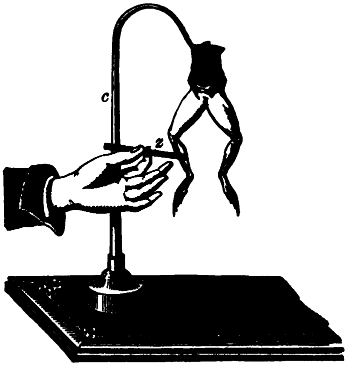
Fig. 263.

Illuminated Pane.

The "electric gun" is filled with a mixture of oxygen and hydrogen gases. A spark causes them to combine with a loud explosion and form water. The sulphurous smell which accompanies the working of an electrical machine, and is noticed in places struck by lightning, is owing to the production of ozone, a peculiar form of the oxygen of the air.

A slight charge from a Leyden jar produces a contraction of the muscles and a spasmodic sensation in the wrist. A stronger one becomes painful, and even dangerous.

Fig. 264.



Galvani's Experiment.

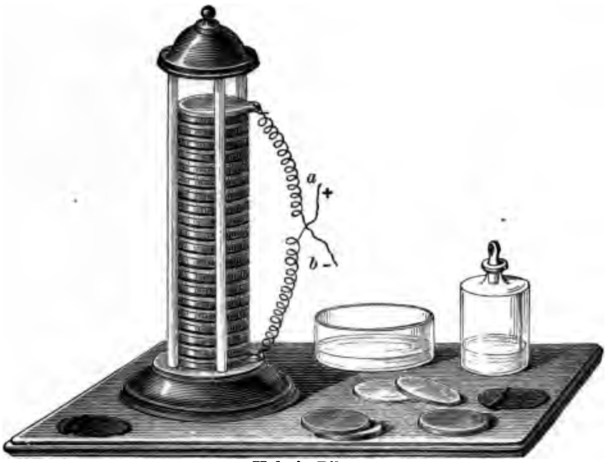
VOLTAIC ELECTRICITY.

This name is given in honor of the Italian physicist, Volta, who made the first discoveries in this branch of electricity.

In the year 1790, Galvani was engaged in some experiments on animal electricity. For this purpose, he used frogs' egs as electroscopes. He had ung several of these upon copper hooks from the iron railing ' the balcony, in order to see what effect the atmospheric

electricity might have upon them. He noticed, to his surprise, that when the wind blew them against the iron supports, the legs were convulsed as if in pain. After repeated experiments, Galvani concluded that this effect was produced by what he termed animal electricity, that this electricity is different from that caused by friction, and that he had discovered the agent by which the will controls the muscles. Volta rejected the idea of animal electricity, and held that the contact of

FIG. 265.



Volta's Pile.

dissimilar metals was the source of the electricity, while the frog was "only a moist conductor, and for that purpose was not as good as a wet rag." He applied this view to the construction of "Volta's pile," which is composed of plates of zinc and copper, between which are laid pieces of flannel moistened with an acid or a saline solution (Fig. 265). This theory is substantially the one held at the present time, though we now know that there must be chemical action to continue the supply.

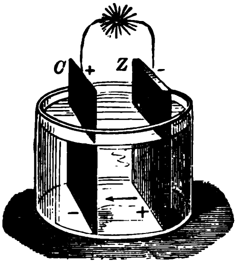
Simple Voltaic Circuit.

If a strip of zinc, coated over with mercury, be put into a mixture of sulphuric acid and water, no perceptible chemical action will be noticed. *But if a strip of* copper or platinum be immersed at the sam

time, and the upper ends of the two pieces of metal be touched together or connected by wires, many little bubbles of gas will be seen on the second strip, forming and rising to the surface. When the experiment is performed in the dark, an almost infinitesimal spark is perceived at the moment the wires are joined.

We can easily form a simple galvanic circuit by placing a silver coin between our teeth and upper lip, and a piece of zinc under our tongue. On pressing the edges of the two metals together, a peculiar taste will be perceived.

FIG. 266.



A Voltaic Pair.

Two metal plates joined in this way form a voltaic pair. The exposed end of the copper or platinum plate is called the positive pole, and that of the zinc the negative pole of the pair. These names may easily be remembered if we associate the p's with copper and positive, and the n's with zinc and negative. Joining the wires, or otherwise connecting the poles, is termed closing the circuit; and separating them, breaking the circuit. A cup prepared for such an experiment is called a voltaic cell.

Action in the Voltaic Cell.

Zinc is far more easily acted upon by sulphuric acid than copper is. Each molecule of the acid is composed of two atoms of hydrogen, one of sulphur, and four of oxygen. This may be expressed by the symbol, H_2SO_4. When the acid, mixed with water, acts on zinc (Zn), its hydrogen is set free, and a new substance, called zinc sulphate, is produced. Its symbol is $Zn\,SO_4$. It is at once dissolved in the water, leaving a fresh surface of metal to be attacked by the acid. It is thought that each molecule of liquid between the copper and zinc becomes polarized, then decomposed, giving up its H_2 to its neighbor on the side toward the copper, and its SO_4 to its neighbor on the side toward the zinc. The H_2 liberated, in contact with the copper, gathers in bubbles f gas; the SO_4, in contact with the zinc, unites with this metal. t the copper plate, chemical energy is transformed into eleccal energy. If the exposed ends of the two plates be examd with a sufficiently delicate electroscope, while they are still

separate, it is found that the copper is electrically at higher potential than the zinc. When they are connected, neutralization instantly takes place, but the action of the acid renews the potential of the copper, so that the process is continuous as long as the zinc can be dissolved by the acid.

With what inconceivable rapidity must these successive changes take place in an iron wire to transmit the electric energy, as in actual experiments, from Valentia, Ireland, across the bed of the Atlantic and the American continent to San Francisco and return, a distance of 14,000 miles, in two minutes! In fact, it far surpassed the velocity of the earth's rotation, by which we measure time, and leaving Valentia at 7:21 A.M., February 1, it reached San Francisco at 11:20 P.M., January 31.

The Electric Current.

The term "current" is applied to this continuous neutralization and renewal of electric potential in the closed voltaic circuit. The current is said to "flow" through the conducting wire from the copper at high potential toward the zinc at low potential, just as water flows from an elevated reservoir through a pipe toward a lower reservoir. There is no actual transfer of matter, no current of fluid; but only by analogy we may call it a current of energy transmitted through the entire thickness and length of the conducting wire. By analogy also the current is said to pass through the cell from zinc to copper, thus completing its circuit.

From the earliest times in which the knowledge of electricity began to be definite, impostors and half-educated people circulated marvelous stories about its value as a panacea for all kinds of disease. Many supposed that deafness and dimness of sight might be cured by the use of the electric spark. Franklin remarked of this, "it will be well if perfect blindness be not the consequence of the experiment." In the hands of experienced physicians electricity has been used with good effect, but to-day, as in Franklin's time, the name often serves as a cloak for ignorance or trickery.

The Volt.

We measure the difference of temperature between two bodies in degrees on the thermometer scale, or the difference of level between the surfaces of two reservoirs in feet or meters. These are the *accepted units of* measurement. In like manner, for measurin

the difference of potential between two bodies, a unit called the volt has been selected, in honor of Allesandro Volta, an Italian physicist, who was born in 1745. In 1793, he communicated to the Royal Society of London an account of his important experiments, on which the modern science of electricity has been largely built.

In the simple voltaic cell already described, when freshly set in action, the difference of potential between its poles is about one volt. The force due to difference of potential is called electro-motive force, and is always measured in volts.

The difference of potential between the discharging rods of a Voss electrical machine when giving long sparks is often several hundreds of volts. When passed through the body, such momentary currents are painful. The potential of the air during a thunder-storm quickly changes through thousands of volts. The voltaic cell furnishes a current that is exceedingly steady in comparison with the stream of sparks from an electrical machine, but of only small electro-motive force. Frictional electricity is sudden, noisy, convulsive; voltaic is gentle, silent, yet powerful. The one is like a quick, violent blow; the other like a steady, uniform pressure. The effect of the one is comparable to that of a blazing fire; the other, a summer breeze. Lightning leaps across miles of air; the voltaic current will pass through a conductor from England to California rather than spark across half an inch of air. The most powerful frictional machine would be insufficient for telegraphing; while signals have been sent across the ocean with a tiny battery composed of "a gun-cap and a strip of zinc, excited by a drop of water the bulk of a tear." "Faraday immersed a voltaic pair, composed of a wire of platinum and one of zinc, in a solution of four ounces of water and one drop of oil of vitriol. In three seconds this produced as great a deviation of the galvanometer needle as was obtained by thirty turns of the powerful plate-glass machine. If this had been concentrated in one millionth of a second, the duration of an electric spark, it would have been sufficient to kill a cat; yet it would require '00,000 such discharges to decompose a grain of water."

Every conductor opposes resistance to the electric current. strong current at one end of a long telegraph wire is weak-

ened at the other end. The liquid in the voltaic cell opposes resistance as well as the conducting wire. The strength of current increases in proportion to the electro-motive force that is used and decreases in proportion to the resistance that is met with.

Electrical Resistance.

To measure resistance, a unit called the ohm has been selected, in honor of Dr. G. S. Ohm, a German physicist, who determined the relation existing between current strength, electro-motive force, and resistance. A piece of common copper wire, as thick as the band shown in Fig. 267, and fifty yards long, opposes a resistance of about one ohm. Coils whose resistance in ohms is known are much used in electrical measurement.

The Ohm.

FIG. 267.

To measure the effective current strength obtained from a voltaic cell, a unit called an ampère has been selected, in honor of André Marie Ampère, a French physicist, born in 1775, whose splendid work in electricity was such as to give him the highest rank along with Volta.

The Ampère.*

It is the amount of current obtained when one volt of electro-motive force acts against one ohm of resistance.

With these units electricity can be measured with as much exactness as we measure quantities of rain or water.

A battery consists of two or more voltaic cells so connected as to secure a stronger current than can be obtained from a single cell. According to Ohm's Law, the current strength (C) in ampères is equal to the electro-motive force (E) in volts divided by the resistance in ohms. The resistance is partly in the external conductor (R) and partly in the liquid of the battery (r). The law is expressed in a formula, thus,

A Battery.

$$C = \frac{E}{R + r}.$$

With a large number of cells a battery, therefore, can be arranged either to overcome a large external resistance, or,

* The definitions of electrical units given in the text are not exa enough to furnish more than the most elementary ideas.

when this is small, to do a large amount of work within a liquid.

Polarization within the Battery.

As soon as the action of a battery is well begun, the electro-motive force becomes rapidly diminished because hydrogen tends to collect upon the plate in connection with the positive pole. The bubbles interfere with further action and start a counter electro-motive force which neutralizes much of that in operation. Many different devices have been employed to diminish this evil, and each gives rise to a special kind of battery. Only a few need be described.

FIG. 268.

Potassium Bichromate Cell.

The Potassium Bichromate Battery.

Instead of copper, a pair of plates of carbon are immersed, with a plate of zinc between them, arranged so as to slide into the liquid, or out of it, at will. A solution of potassium bichromate in sulphuric acid and water is used. The sulphuric acid acts on the zinc, and the hydrogen is prevented from forming in bubbles by being combined at once with some of the oxygen which the chromic acid yields.

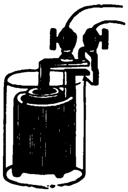
Daniell's Battery. — In this battery there are two fluids separated by a cup of porous earthenware, which does not prevent the passage of the current. In the outer vessel of glass there is a strong solution of copper sulphate ($CuSO_4$), in which a split copper cylinder is immersed. Within this is placed the porous cup, containing a rod of zinc coated with mercury and a mixture of sulphuric acid with water. Zinc sulphate is produced, and the liberated hydrogen decomposes some of the copper sulphate, taking its SO_4 and causing a deposit of metallic copper. Polarization is thus prevented, and for this reason, the Daniell's battery is one of the most constant batteries known.

FIG. 269.

Daniell Cell.

Grove's Battery.—In this the outer cup contains the zinc and dilute sulphuric acid. Within the porous cup a strip of platinum dips into strong nitric acid. The hydrogen decomposes some of the nitric acid, taking oxygen from it to produce water and liberating red fumes of nitric oxide, which are unpleasant and hurtful. This battery gives very high electromotive force.

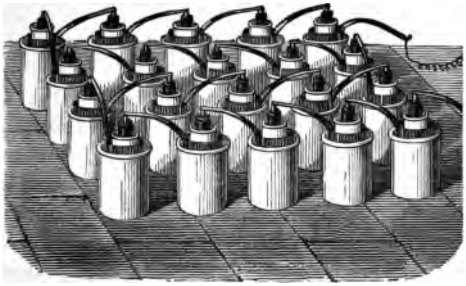
FIG. 270.



Grove Cell.

Bunsen's Battery.—In this rods of carbon are substituted for the strips of platinum used in the Grove battery. Sometimes potassium bichromate solution is substituted for nitric acid in order to avoid the production of nitrous fumes. Fig. 271 shows a Bunsen battery arranged in series.

FIG. 271.



Bunsen Battery.

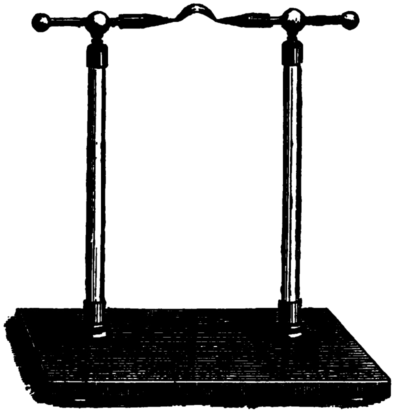
Effects of Voltaic Electricity.

If a current of electricity is passed through a wire too small to conduct it readily, it is converted into heat. The poorer the conducting power of the wire, and hence the greater the resistance, the more marked the effect. With ten or twelve Grove's cups several inches of fine steel wire may be fused; and with a powerful battery, several yards of platinum wire may be made to glow with very brilliant effect, giving a steady light. Torpedoes and blasts are fired on this principle. Two copper wires leading from the battery to the spot are separated in the powder by a short piece of small steel wire. When the circu

is completed, the fine wire becomes red-hot and explodes the charge.

In closing or breaking the circuit, we produce a spark, the size of which depends on the electro-motive force and current strength of the battery. With several cells, beautiful scintillating sparks are obtained by fastening one pole to a file and rubbing the other upon it. When charcoal or gas-carbon electrodes are used with a powerful battery, on slightly separating the points, the intervening space is spanned by an arch of the most dazzling light (Fig. 272). The flame, reaching out from the positive pole like a tongue, vibrates around the negative pole, licking now on this side and now on that. The heat is intense. Platinum melts in it like wax in the flame of a candle, the metals burn with their characteristic colors; and lime, quartz, etc., are fused. The effect is not produced by burning the charcoal points, since in a vacuum it is equally brilliant.

Fig. 272.



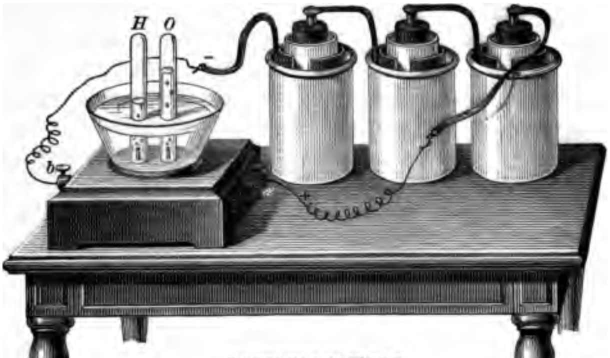
The Arc Light.

To show the varying conducting power of the different metals, fasten together alternate lengths of silver and platinum wire and pass the current through them. The latter will glow, while the former, conveying the electricity more perfectly, will scarcely manifest its presence.

There are two forms of the electric light now used—the arc 'shown in Fig. 272), where the current passes between two car- ›on points; and the incandescent, where the current heats to a lazzling white a carbon strip placed in the circuit. The former employed in lighting streets, railroad stations, and large halls; ıe *latter is* generally used in dwellings, etc., as it gives a softer ʒht, *and is* much more steady. Edison's Lamp consists of a

tiny carbon loop placed in a glass globe from which the air has been so completely exhausted as to leave only $\frac{1}{1000000}$ of an atmosphere. When exposed to the air, the voltaic arc rapidly wastes the carbon points. Electric lamps have therefore been devised that, by a self-acting apparatus, keep the points at a proper distance from each other.

FIG. 278.



Electrolysis of Water.

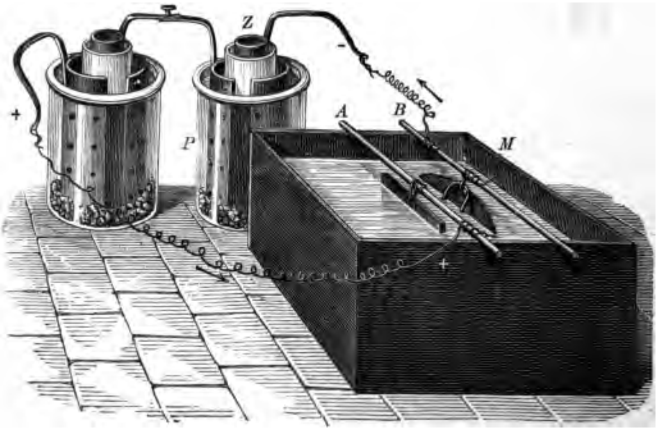
Electrolysis (to loosen by electricity) is the process of the decomposition of compound bodies by the voltaic current. If platinum electrodes be held a little distance apart in a cup of water mixed with sulphuric acid, tiny bubbles will immediately begin to rise to the surface. When the gases are collected, they are found to be oxygen and hydrogen, in the proportion of two parts of the latter to one of the former. If the copper poles be inserted, bubbles will pass off from the negative, but none from the positive pole, since the oxygen combines with the copper wire. That gas has no effect on platinum. The burning of an atom of zinc in the battery develops enough electricity to set free an atom of oxygen at the positive pole. It is interesting to notice that in the battery there is zinc burning, *i. e.*, combining with oxygen, but without light or heat; in the electric light the real force of the combustion is revealed. We may thus transfer the light and heat to a great distance from the place where they take their origin. The transmission of energy thr

to a distance is better effected through electricity than through any other agency. Much ingenuity has been expended on machines for this purpose.

In the electrolysis of compounds, their elements are found to be in different electrical conditions. Hydrogen and most of the metals go to the negative pole, and are electro-positive. Oxygen, chlorine, sulphur, etc., go to the positive pole, and are therefore electro-negative.

Any battery-cell subjected to electrolysis is called a secondary cell. Several such cells form an accumulator or storage battery. Faure's accumulator consists of two lead plates coated with red lead, rolled together with flannel between them, and immersed in dilute sulphuric acid. A current of electricity passed through such a cell changes a part of the red lead on the positive plate into peroxide of lead; and a part of the red lead on the negative plate into spongy metallic lead. A battery of these cells when freshly charged will retain its energy and produce a sustained current when desired.

FIG. 274.



Electrotyping.

Electrotyping is the process of depositing metals from their solution by electricity. It is used in copying medals, wood-cuts, types, etc. An impression of the object is taken with gutta-

percha or wax. The surface to be copied is brushed with black-lead to render it a conductor. The mold is then suspended in a solution of copper sulphate, from the negative pole of the battery, and a plate of copper is hung opposite on the positive pole. The electric current decomposes the copper sulphate; the metal goes to the negative pole and is deposited upon the mold, while the acid, passing to the positive pole, dissolves the copper, and preserves the strength of the solution. While the plate is hanging in the solution there is no noise heard or bubbling seen. The most delicate sense fails to detect any movement. Yet the mysterious electric force is continually drawing particles of ruddy, solid copper out of the blue liquid, and, noiselessly as the fall of snow-flakes, dropping them on the mold; producing a metal purer than any chemist can manufacture, spreading it with a uniformity no artist can attain, and copying every line with a fidelity that knows no mistake.

Electro-plating is the process of coating with silver or gold by electricity. The metal is readily deposited on German silver, brass, copper, or nickel silver (a mixture of copper, zinc, and nickel). The objects to be plated are thoroughly cleansed, and then hung from the negative pole in a solution of silver, while a plate of silver is suspended on the positive pole. In five minutes a "blush" of the metal will be deposited, which conceals the other metal and is susceptible of polish.

Place in a large test-tube a silver coin with a little nitric acid. If the fumes of the decomposed acid do not soon rise, warm the liquid. When the silver is dissolved, fill the tube nearly full of soft water. Next drop hydrochloric acid into the liquid until the white precipitate (silver chloride) ceases to fall. When the chloride has settled, pour off the colored water which floats on top. Fill the tube again with soft water; shake it thoroughly; let it settle, and then pour off as before. Continue this process until the liquid loses all color. Finally, fill with water and heat moderately, adding potassium cyanide (it should be remembered that this substance is exceedingly poisonous) in small bits as it dissolves, until the chloride is nearly taken up. The liquid is then ready for electro-plating. Thoroughly cleanse a brass key, hang it from the negative pole of a small battery and suspend a silver coin from the positive pole. Place these in

the silver solution, very near and facing each other. When well whitened by the deposit of silver, remove the key and polish it with chalk. In the arts the polishing is performed by rubbing with "burnishers." These are made of polished steel, and fit the surfaces of the various articles upon which they are to be used. It is said that an ounce of silver can be spread over two acres of surface. A well-plated spoon receives about as much silver as there is in a ten-cent piece. The only method of deciding accurately the amount deposited is by weighing the article before and after it is plated. A vessel may be "gold-lined" by filling it with a solution of gold, suspending in it a slip of gold from the positive pole of the battery, and then attaching the negative pole to the vessel. The current passing through the liquid causes it to bubble like soda-water, and in a few moments deposits a thin film of gold over the entire surface.

With a single cell no special sensation is experienced when the two poles are held in the hands. With a large battery a sudden twinge is felt, and the shock becomes painful and even dangerous, especially if the palms are moistened with salt or acid water to increase the conduction. Rabbits which had been suffocated for half an hour, have been restored by an application of a strong voltaic current.

TRANSFORMATIONS OF ELECTRIC ENERGY.

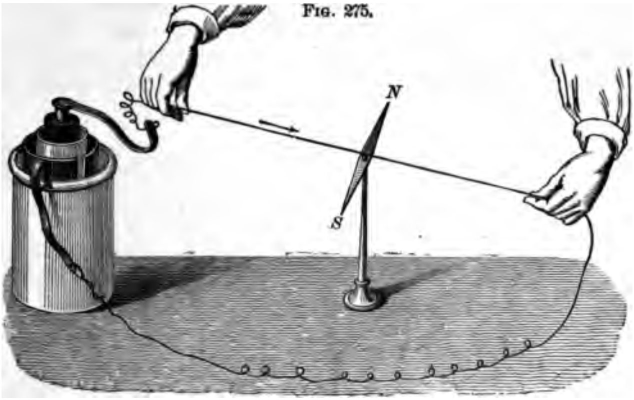
Effect of a Voltaic Current on a Magnetic Needle.

If a wire conducting an electric current be placed over a poised magnetic needle, this tends to place itself at right angles to the wire.

Assuming the direction of the current to be northward, the north pole of the needle will be turned toward the left. The same effect will be produced if the current pass southward under the needle, or vertically downward on the north side of it, or vertically upward on the south side of it. By reversing these conditions, the north pole of the needle will be turned toward the right. The play of the needle becomes thus a test of the presence and direction of an electric current. The delicacy of this test is greatly increased if the wire, properly insulated, be coiled into a ring with many turns, at the center of which the needle is pivoted or suspended.

Ampère gave a very convenient rule for determining the direction of the current from the motion of the magnetic needle.

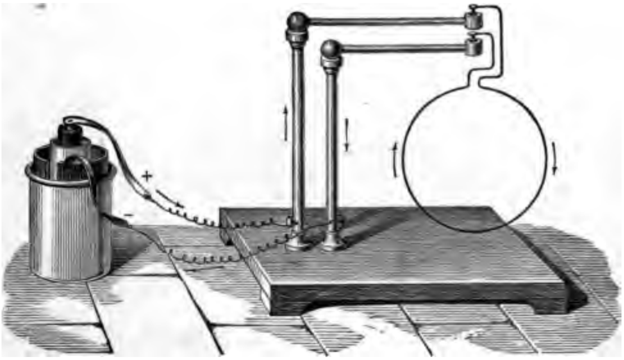
FIG. 275.



Effect of Current on Needle.

Imagine the current to be like a stream of water, with a little swimmer in it, facing the needle and swimming along with the

FIG. 276.



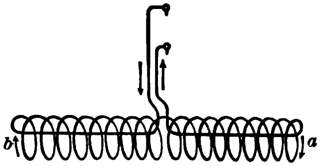
Pivoted Hoop of Conducting Wire.

current. The north pole of the needle will always turn toward his left. The pupil should try the experiment and test it in all *possible ways*.

Let a copper-wire hoop be pivoted, as shown in Fig. 276, so that its plane is in a north and south direction. On passing an electric current, it slowly turns until its plane assumes an east and west position. One side of the wire is like the north pole of a magnet and the opposite side like the south pole. If, instead of a single hoop, we use a coil of wire (Fig. 277), the action is more prompt. By applying Ampère's rule, we easily find which end of the coil acts like a north magnetic pole.

A Wire bearing a Current acts like a Magnet.

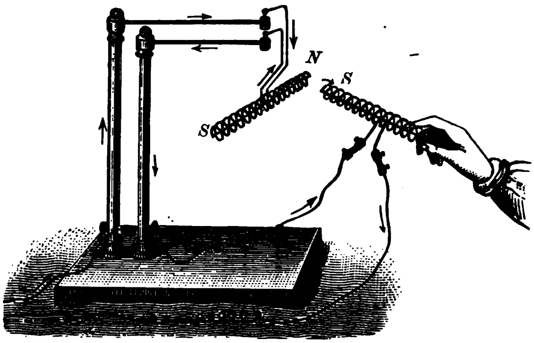
Fig. 277.



Pivoted Helix of Wire.

The end of a second conducting coil when brought near is attracted or repelled just as if each were a magnet (Fig. 278). We may conclude that a current-bearing wire is in the midst of

Fig. 278.



Two Helices acting like Magnets.

a magnetic field, which is due to the presence of the current. The left side of one coil being nearest the right side of the other, if the current pass in the same direction in both, opposite kinds of magnetism are produced in the space between them, and hence they attract. If the current in one be reversed, they repel.

The Tangent Galvanometer.

Any instrument designed to measure the strength of an electric current is called a galvanometer. Of the many varieties, the tangent galvanometer is the most important. It consists of one or more coils of insulated wire wound upon a wooden hoop, at the center of which a small magnetic needle is pivoted or suspended

FIG. 279.

The Tangent Galvanometer.

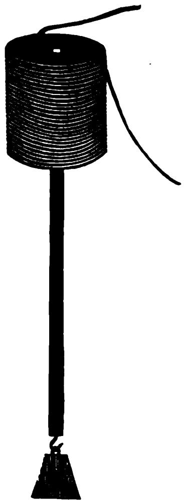
(Fig. 279). The plane of the coils is made to coincide with that of the magnetic meridian. The earth's magnetism tends to keep the needle in this plane. The magnetic effect of a current tends *to make it* assume a position across this plane. *Obeying both forces, it* assumes an oblique position, so as to

make a measurable angle with the meridian. The strength of current is proportional to the tangent of this angle.

The Electro-magnet.

If a current be passed through a coil held vertically (Fig. 280), a rod of soft iron placed below will be drawn up into the coil, springing up as if endowed with life at the moment the current begins. It drops as soon as the circuit is broken. Thus is realized in science the fabulous story of Mahomet's coffin, which is said to have been suspended in mid-air.

FIG. 280.



A Magnetic Mahomet's Coffin.

Let a pair of such coils be fixed around the arms of a U-shaped rod of soft iron. This becomes a strong horseshoe magnet, whose strength comes and goes as the current is made or broken. It is therefore called an electro-magnet. Such magnets have been made strong enough to sustain a weight of several tons attached to the armature below.

Electricity and magnetism were studied as distinct branches until 1820, when Oersted of Copenhagen discovered the phenomenon shown in Fig. 275. This was published everywhere, and excited the deepest interest of scientific men. In the fruitful mind of Ampère the experiment bore abundant fruit. He discovered that two parallel wires conveying an electric current in the same direction attract each other, and when in opposite directions, repel each other. From this he generalized the entire subject. Prof. Henry next exhibited the wonderful power of the electro-magnet, and invented the electro-magnetic engine. Scientific men in all parts of the world were now gathering the material necessary for the invention of the electric telegraph. It fell to Samuel F. B. Morse to make this knowledge practical, and in 1837 he exhibited in New York a working instrument. An experimental line between Washington and Baltimore was completed in 1844, and, on May 27 of that year, was sent the first message ever forwarded by a recording telegraph.

The Electro-magnetic Telegraph.

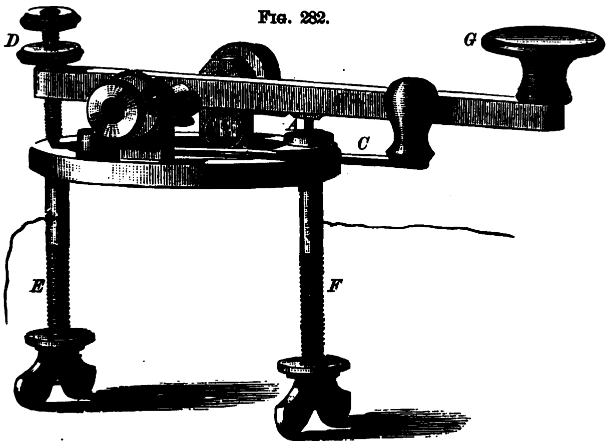
The electro-magnetic telegraph depends on the principle of closing and breaking the circuit at one station, and thereby making and unmaking an electro-magnet at the station with which communication is held. A single wire is used to connect the two stations. The extremities of the wire extend into the ground, and the earth completes the circuit in which the battery and instruments are included. Each station has a key and a register (or sounder); the former is used for sending messages, and the latter for receiving them.

Fig. 281.

The Electro-magnet.

The key is shown in Fig. 282. *E* and *F* are screws which fasten the instrument to the table, and also hold the two ends of the wire. *F* is insulated by a ring of vulcanite where it passes through

Fig. 282.

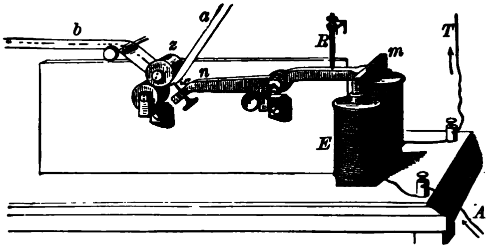


The Telegraph Key.

the table *and the* metal plate *B*. *H* is a lever with a finger *button G, a spring I,* to keep it lifted, and a screw D, t

regulate the distance it can move. At *A* is a break between two platinum points, which form the real ends of the wires. When *G* is depressed, the circuit is complete, and when lifted, it is broken. *C* is a circuit-closer that is used when the key is not in operation; the arm being pushed under *A*, touches the platinum wire, and so completes the circuit. It is pushed

FIG. 283.



The Register.

out whenever the operator manipulates *G*. Then, by moving *G*, he can "close" or "open" the circuit at pleasure. He thus sends a message.

The register contains an electro-magnet, *E* (Fig. 283). When the circuit is complete, the current, passing through the

TABLE OF MORSE'S SIGNS.

a	· —	j	— · — ·	s	· · ·
b	— · · ·	k	— · —	t	—
c	· · ·	l	——	u	· · —
d	— · ·	m	— —	v	· · · —
e	·	n	— ·	w	· — —
f	· — ·	o	· ·	x	· — · ·
g	— — ·	p	· · · · ·	y	· · · ·
h	· · · ·	q	· · — ·	z	· · · ·
i	· ·	r	· · ·	&	· · · ·

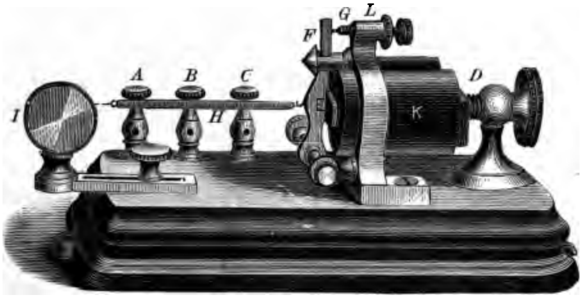
oils of wire at *E*, attracts the armature *m*. This elevates *n*, *he other* end of the lever *mn*, and forces the rounded point *x*

firmly against the soft paper *a*. As soon as the circuit is broken, *E* ceases to be a magnet, and the spring *R* lifts the armature, drawing the point from the paper. Clock-work attached to the rollers at *z* moves the paper along uniformly beneath the point *x*. When the circuit is completed and broken again instantly, there is a short dot made on the paper. This is called *e*; two dots, *i*; three dots, *s*; four dots, *h*. If the current is closed for a longer time, the mark becomes a dash, *t*; two dashes, *m*; a dot and a dash, *a*.

A skillful operator becomes so accustomed to the sound that the clicking of the armature is perfectly intelligible. He uses, therefore, simply a "sounder," *i. e.*, a register without the paper and clock-work attachment. Indeed, the register has now gone almost entirely out of use, and every operator is required to read by sound.

When the stations are more than fifty or sixty miles apart, the current becomes generally too weak to work the register.

FIG. 284.



The Relay.

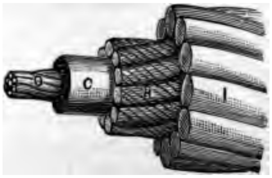
By substituting the relay for it in the line circuit, the force of a local battery may be employed to work the sounder or register. In Fig. 284, which represents a relay, *D* is connected with the line wire, and *C* with the ground wire; *A* is connected with the positive pole of the local battery, and *B* with the register or sounder, and thence with the negative pole of this battery. The main current passes in at D, traverses the fine wire of the electro-magnet, *K*, and thence passes out at C

the ground. The armature E, playing to and fro as the current from the distant station passes through or is cut off, moves the lever F. This works on an axis at the lower end, and is drawn back by the spring H, which is regulated by the thumb-screw I. As E is attracted, the circuit at G is closed; the current from A traverses a wire underneath, up F, and down L, and back through another wire underneath to B; thence to the electro-magnet of the sounder, which therefore attracts its armature.

The operator who sends the message simply completes and breaks the circuit with the key; the armature of the relay, at the station where the message is received, vibrates in unison with these movements; the register or sounder repeats them with greater force; and the second operator interprets their meaning. The simple telegraph instrument is but one of a multitude of applications that have been made of the electro-magnet. By various ingenious devices it has become possible to send two, or even four, messages with reasonable rapidity over the same line at the same time. By one system, devised by Mr. Delany, as many as seventy-two circuits have been operated with a single instrument at the rate of two or three words per minute. The message is often printed at the moment it is received. From the Stock Exchange in New York hundreds of printed reports are thus sent at the same time to offices in various parts of the city.

Ocean Cables. The Atlantic and Indian Oceans have been spanned with cables of insulated wire for the transmission of telegraphic messages. The cable must be well insulated and very strong. In the middle is a bundle of copper wires, O (Fig. 285); this is buried within a sheathing of gutta-percha, C; around this is a group of cords of tarred hemp, H, to protect the gutta-percha; and, to give still further protection and strength, fifteen or twenty iron wires are twisted around the whole, so as to make it a rope about an inch thick.

FIG. 285.

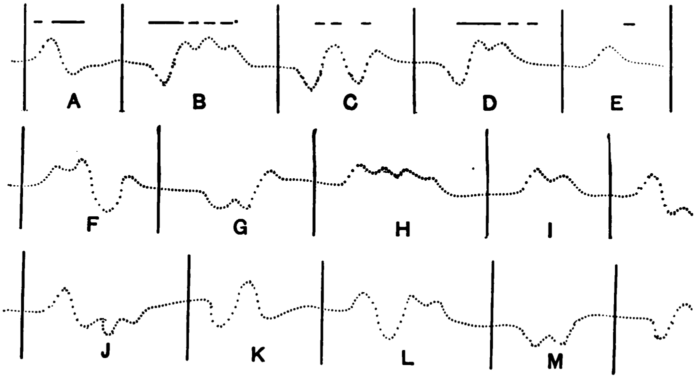


A Piece of Ocean Cable.

In signaling over a long cable, allowance has to be made

for the great resistance of the long wire, and the slowness with which the circuit has to be operated. Instead of using a relay or sounder, it is necessary to use a delicate galvanometer as a receiver. A beam of light is reflected from a little mirror attached to the magnetic needle, and the swinging of the bright spot on a screen is interpreted as an alphabet. Or, a fine glass

Fig. 286.



Siphon-recorder Alphabet.

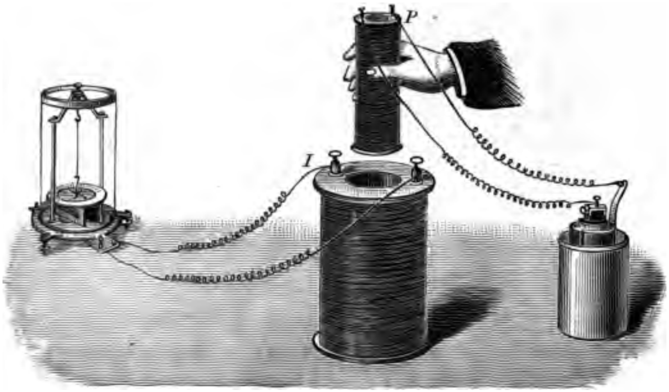
siphon tube is attached to a movable galvanometer coil which swings between the poles of an electro-magnet. Its short arm dips into a vessel of ink which is insulated and can be electrified. The long arm has its end over a strip of paper moved by clock-work. The electrification of the ink causes it to issue in fine drops over the moving paper, and a sinuous line is recorded. This "Siphon-recorder" alphabet is partly shown in Fig. 286.

Current Induction.

We have seen that two magnets react upon each other when brought close together, and that current-bearing wires are magnets. If a current-bearing wire be moved swiftly past another wire forming a closed circuit but having no battery included, it renders this momentarily magnetic, and an evanescent current passes through it. Let the coil *P* (Fig. 287), which forms a closed circuit with the battery, be thrust into the coil *I*, which forms a closed circuit with the galvanometer. Instantly the needle turns, and then *comes back to rest*. Suddenly withdraw P. The needle turn

in the opposite direction, and again comes back to rest. *P* is called the primary coil; *I*, the secondary or induction coil, because currents in it are induced by the motion of *P*. The current in *I* is opposite in direction to that of *P* when this is thrust in, and in the same direction when *P* is withdrawn. Similar effects are obtained by making and breaking the circuit in *P*.

FIG. 287.



Current Induction.

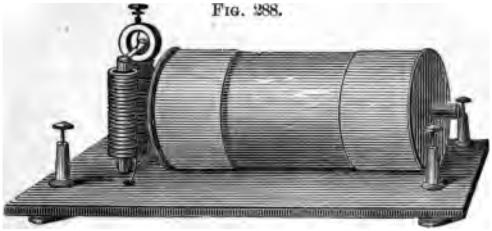
Ruhmkorff's Induction Coil.

Ruhmkorff's induction coil is provided with an automatic circuit-breaker, consisting of an electro-magnet whose current passes through a spring to which the armature is attached. When there is no current this spring touches a "contact point" which forms part of a circuit. On dipping the zinc into the acid of the battery, the current excites the electro-magnet. This attracts the armature, and thus removes the spring from the contact point. The circuit is hence broken, and the spring draws back the armature, making contact again. The vibration of the armature thus produces rapid repetitions and reversals of the current in the secondary coil. The primary coil contains a bundle of iron wires, which become magnetic and react upon the coil, causing its magnetism, and therefore its induced current, to become stronger. The insulated wire of the secondary coil is long and fine, sometimes a hundred miles or more in

length. The electro-motive force of the secondary current is enormously greater than that of the primary.

The largest induction coil ever constructed was made for Mr. Spottiswoode, an English physicist. Its secondary coil contained 280 miles of wire, wound in 340,000 turns, and its resistance exceeded 100,000 ohms. When worked with a Grove battery of thirty cells, it gave a spark forty-two inches long, or considerably more than a yard in length. Coils containing fifty miles of wire are not uncommon; they yield sparks a foot or

FIG. 288.



Induction Coil.

more in length. A Leyden jar interposed in the secondary circuit of such a coil is charged and discharged so rapidly as to make almost a continuous sound.

Connected with the poles of the battery is a condenser, which still further heightens the effect of the coil.

The induction coil is used for many purposes requiring high electro-motive force, and is usually more reliable than any machine generating electricity by friction. Beautiful effects are obtained by passing sparks from it through Geissler tubes. These are made of glass, and contain rarefied gases or vapors. The spark when passing through rarefied hydrogen assumes a brilliant red tint; through nitrogen, a gorgeous purple. With the proper degree of rarefaction, it becomes stratified into bands across the tube.

The Aurora Borealis.

The aurora is a luminous phenomenon, which appears most frequently about the poles of the earth, and more particularly about the boreal or northern pole, whence its name.

At the close of twilight a vague and dim light appears in

the horizon in the direction of the magnetic meridian. This light gradually assumes the form of an arch of a pale yellowish color, having its concave side turned toward the earth. From this arch streams of light shoot forth, passing from yellow to pale green, and then to the most brilliant violet purple. These rays or streams of light generally converge to that point of the

FIG. 289.

Aurora Borealis.

heavens which is indicated by the dipping-needle, and they then appear to form a fragment of an immense cupola, as shown in Fig. 289.

Since the aurora is always accompanied by a disturbance of the magnetic needle, and is generally arranged in the direction of the dip, and acts upon telegraph wires, it is inferred that it is due to electrical action. Such is at present the generally received belief.

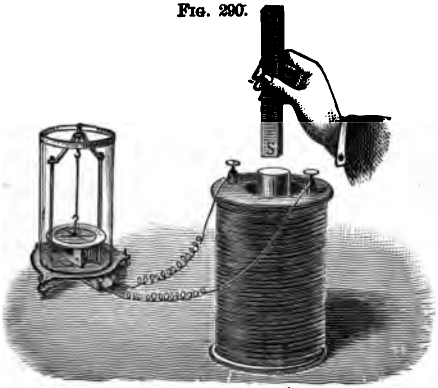
Magneto-Induction.

In order to produce alternating currents in a secondary coil, it is sufficient merely to move a magnet in the neighborhood of the coil that is to be affected. Let one pole of the magnet, *NS* (Fig. 290), be waved over an end of the coil. The currents induced will be manifested in the swinging of the galvanometer needle. This effect is intensified by putting a rod of soft iron within the coil and bringing the magnet pole alternately toward and away from it.

The Telephone.

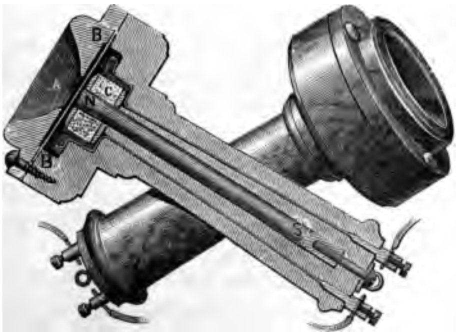
The telephone is an instrument for utilizing magneto-electric currents and reproducing speech by their aid. Within a handle of vulcanite is a permanent magnet (Fig. 291), around one pole, *N*, of which is an insulated coil, *C*, connected with the binding posts at the other end. A thin disk of soft iron, *BB*, is fixed across near the encircled magnet pole, and a mouth-piece, *A*, serves to direct the sound of the voice against the disk, which is thus made to vibrate. Disturbances are produced in the strength of the magnet, and corresponding currents traverse the wire. Passing through the coil of the distant telephone, they vary the strength of its magnet. Minute clicking sounds are produced as the molecules of the magnet yield to these disturbances. The disk re-enforces these like a sounding-board, and gives out vibrations to the air, with such rapidity as to constitute a faithful reproduction of what was talked into the transmitting telephone. It should be observed that the presence of a disk is not necessary for th perception of sour *from the receiving* telephone. The motion is probably amo

FIG. 290.



Magneto-electric Currents.

FIG. 291.



The Telephone.

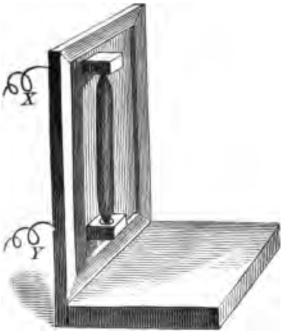
the molecules of the steel magnet, and conducted from them to the disk if this be added.

The telephone described above is the simplest that can be made. Many improvements have been effected in the instrument. The transmitting telephone is now generally made in such manner as to send an induced current, like that of the Ruhmkorff coil, through the line wire to the receiver.

The Microphone.

The microphone is a modification of the telephone transmitter. It consists of a rod of gas carbon whose ends rest loosely in cups hollowed out of the same material, and these in turn fixed upon a sounding-board. The current from a battery passes through the microphone carbons and through a receiving telephone. If the sounding-board be made to vibrate in the least, whether by sound-waves or by slight mechanical motion, variations are produced in the pressure of the rod against its cups. Two pieces of carbon firmly in contact conduct electricity moderately well; but if the pressure between them is diminished, the resistance is increased and the current becomes fainter. The microphone is thus the last refinement of the telegraph combined with the telephone receiver. The sound of the voice, the patter of a fly's foot in walking over the sounding-board, or the gentlest ticking of a watch rested upon it, are thus made audible in a telephone many miles away.

FIG. 292.



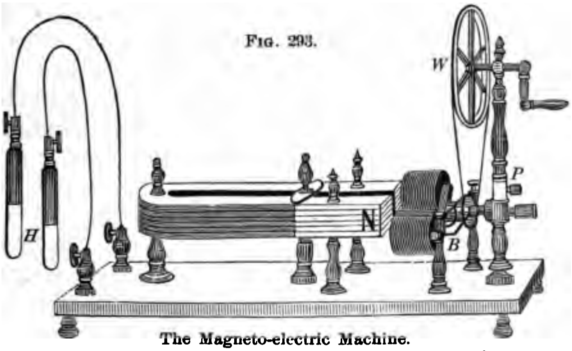
Microphone.

The Magneto-electric Machine.

If the magnet represented in Fig. 290 be fixed and the coil be swept past it, the effect is the same as if the coil were fixed and the magnet swept past it. The magneto-electric machine consists of a powerful horseshoe magnet, through whose field a pair of connected coils is made to rotate. This pair is called the *armature.* Each coil contains a core of soft iron, which acquires and *then* loses magnetism, as it approaches, passes, and then

recedes from a pole of the permanent magnet. In the coil, these rapid variations of magnetic strength produce alternating currents whose electro-motive force is determined by the speed of rotation and the strength of the magnetic field. The two ends of the coil are connected with insulated plates of metal on opposite sides of the axle. On each of these a conducting spring presses, which carries the currents to the handles, *H*. This arrangement, called a commutator, is so adapted as to secure but one direction to the currents in the main wires. On taking hold of the handles while the shaft is rotated rapidly, a series

Fig. 293.



The Magneto-electric Machine.

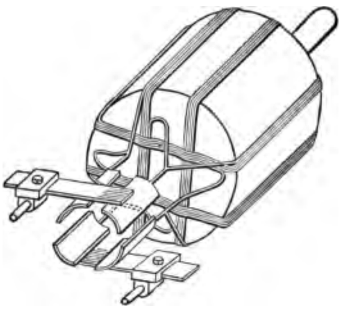
of convulsive shocks is experienced. The machine represented in Fig. 293 is known as Clarke's machine, and was one of the first of its kind invented. Many improvements were made subsequently. In 1866, Mr. Wilde discovered that if the induced current were passed through the coil of an electro-magnet, the strength produced in this was far greater than that of the permanent magnet employed. An additional and larger armature was made to rotate in front of this electro-magnet, and the current induced in it was made to excite a second and still larger electro-magnet, whose armature then generated currents very much stronger than any previously known. Such a machine, driven by a steam-engine of 15-horse power, produces an electric light dazzling as the noonday sun, throwing the flame of the street-lamps into shade at a quarter-mile distance. Its heat is sufficient to fuse a ¼-inch bar of iron fifteen inches long or sever

feet of No. 6 iron wire.—"A Yankee once threw the industrial world of Europe into a wonderful state of excitement by announcing a new theory of perpetual motion based on the magneto-electric machine. He proposed to decompose water by the current of electricity; then burn the hydrogen and oxygen thus obtained. In this way he would drive a small steam-engine, which, in turn, would keep the magneto-electric machine in motion. This would certainly be a splendid discovery. It would be a steam-engine which would prepare its own fuel, and, in addition, dispense light and heat to all around."—HELMHOLTZ.

The Dynamo-electric Machine.

For the generation of currents to be employed in electric lighting it is necessary that they shall be continuous rather than intermittent. The name dynamo is applied to a development of the magneto-electric machine that accomplishes this result. The armature coils, in one type of these machines, are wound lengthwise upon a drum or cylinder, Fig. 294, which is revolved between the poles of a powerful electro-magnet called the field-magnet. On this drum a large number of coils may be wound, each with its own pair of commutator plates, these being so close together that the interval between two successive currents is imperceptible. In Fig. 295, the end of the cylinder and of the group of commutator plates are seen between the large pole-pieces, *N* and *S*, of the field-magnets. The current is conducted off by the springs or "brushes," and passes through the coils of the field-magnet before reaching the main-line wire. The pole-pieces never quite lose their magnetism, even after the machine is at rest. The energy of the induced current is at first wholly absorbed in exciting the field-magnet. This action, even though almost infinitely weak at first, increases until the magnet is as strong as possible; after which the energy is expended in doing work on the main circuit.

FIG. 294.



Drum Armature and Fore-part Commutator.

In the frontispiece is a picture of the Weston Dynamo, such as is used for producing the electric lights on the great bridge between New York and Brooklyn. Each pole-piece is attached to two coils which are so wound that both have the same effect on it. The end of the drum armature is covered with radiating conductors, which connect the coils with the commutator plates. One of the brushes is seen pressing on these plates, and is connected with the insulated wire that conducts the current away.

Fig. 295.

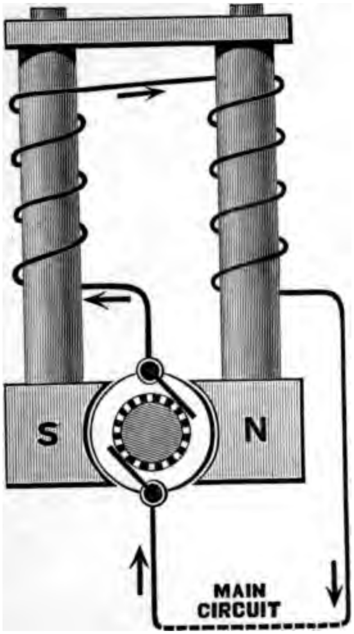


Diagram of a Series Dynamo.

The Electric Light.

According to the method adopted in winding the armature, a dynamo-machine may give currents of high or of low electro-motive force. Two corresponding kinds of lamp are used. To produce the arc light, a current of high electro-motive force is sent through a pair of carbon rods, which are then drawn slightly apart. Particles of carbon are made white-hot, and even turned into vapor, which is thrown from one rod to the other in the direction of the current. The path of the glowing vapor is curved, and hence this is called the voltaic arc. It is the most brilliant artificial light known, but unsteady because the arc leaps from side to side as the carbons become wasted away. An automatic regulator is employed to keep them at the proper distance apart. The arc light is excellent for lighting streets, halls, and other large public places. For domestic use, the incandescent lamp is better. In this a current of low electro-motive force passes through a filament of carbon inclosed in a globe from which most of the air has been withdrawn. The filament glows

with a soft and steady light, which is much inferior in brilliancy to the arc light. Although only $\frac{1}{1\,000\,000}$ of the air remains in the globe, the filament is slowly burned away, and has to be replaced with a new one.

Thermo-electricity.

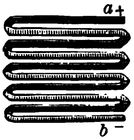
In the electric lamp the energy of a current is changed into heat and light Conversely, heat and light (radiant energy) may be changed into electric energy. If the end of an iron wire be connected with that of a copper or German-silver wire, the other ends being attached to a galvanometer, the needle will swing aside when the joined ends are heated. This effect is increased if the junction be made with bismuth and antimony. A current flows at the junction from bismuth to antimony, thence through the galvanometer back to the bismuth.

A thermo-electric pile consists of alternate bars of antimony and bismuth soldered together, as shown in Fig. 296. When mounted for use, the couples are insulated from each other and inclosed in a copper frame, *P*. If both faces of the pile are equally heated, there is no current. The least variation of temperature, however, between the two is indicated by the flow of electricity. Wires from *a*, the positive pole, and *b*, the negative, connect the pile with the galvanometer. This furnishes a test of change of temperature. A fly walking over the face of the pile by its warmth will move the needle, if the galvanometer be very delicate. When skillfully used, the thermopile serves as a very sensitive thermometer.

Fig. 296.

Thermopile.

Fig. 297.



The Bolometer.

The bolometer is an instrument devised for the detection of very faint variations of temperature. A platinum or iron wire opposes much more resistance to the passage of an electric current when hot than when cold. The current is made to divide between two conductors. These are connected by a cross-wire, or "bridge," with a galvanometer interposed. If the current in the two branches be equal, the galvanometer is not affected; but, if

unequal, a cross-current deflects the galvanometer needle. By heating one branch slightly the balance is disturbed, and the difference of temperature is read in the deflection of the needle.

This instrument was invented by Professor Langley at the Alleghany Observatory near Pittsburg. It was used in examining the invisible parts of the solar spectrum, where lines and bands were discovered whose presence could not be detected with the most delicate thermopile. The invisible part of the spectrum was thus found to be much more extensive than the visible part, while the most intense heat as well as light is found in the region colored greenish-yellow. The bolometer is capable of revealing a change of temperature of .00001° C. Professor Langley has discovered by this means that the highest temperature of the moon scarcely, if at all, exceeds that of the human body, and that the temperature of outer space is nearly as low as the absolute zero of temperature, $-273°$ C.

Animal Electricity.

The human body is often electrified. Many animals, especially when angry or otherwise excited, give evidence of being electrified. Certain fish have the property of giving, when touched, a shock like that from a Leyden jar. The torpedo and the electrical eel are most noted. The former is a native of the Mediterranean, and its shock was anciently prized as a cure for various diseases.

The only species of electric eel known, inhabits the rivers of the northern parts of South America; it attains a length of five or six feet, and is brown and yellowish. The electric apparatus which has rendered this fish so celebrated, occupies the space between the pectoral fins and the tail, for a large part of the lower bulk of the body. The organs are four in number, two on each side; the upper and larger organ being separated from the lower by a thin stratum of muscle and membrane, and the organs of one side are distinct from those of the other. The apparatus consists of an assemblage of membranous, horizontal plates, nearly parallel, and intersected by delicate vertical plates. The cells thus formed are filled with a glutinous matter. The septa, according to Hunter, are one thirtieth of an inch from each other. One inch in length contains two hundred and forty cells, giving a very great surface to the electric organ. The system is abundantly supplied with nerves from the tw

hundred pairs of ventral spinal nerves, but not from those nerves from which the electric system of the torpedo is supplied. The electric eel seems to be a mere appendage to the anterior part of its battery for moving it about, as all other organs are confined to a very small space; and the nerves supplying the electric organs are much larger than those sent to any sensory or motor organs. According to Humboldt, the South American Indians capture these eels by driving horses and mules into the water inhabited by them. The electric power of the eels being exhausted on the quadrupeds, the former are harpooned and thrown on shore. The horses suffer greatly, many of them being killed by the electric discharges of the eels, which glide beneath their bodies. By grasping the head of the eel with one hand and the tail with the other, painful and almost insupportable shocks were received in the experiments of Faraday, and a specimen of this fish, forty inches in length, was estimated by him to emit a spark equal to the discharge of a battery of fifteen Leyden jars. This fish is neither voracious nor fierce, but uses its battery to secure its prey, and to defend itself from its numerous enemies.

CHAPTER XI.

APPLICATIONS OF ELECTRICITY.

Barlow's Wheel.

PROBABLY the first electric motor was what is known as Barlow's Wheel. This consisted of a disk of copper mounted on an axis, and so placed that the periphery came between the poles of a horseshoe magnet. When a current was passed from the center to the circumference of this disk, it revolved on its axis, and, conversely, when the wheel was rotated on its axis, a current of electricity was generated.

Jacobi's Motor.

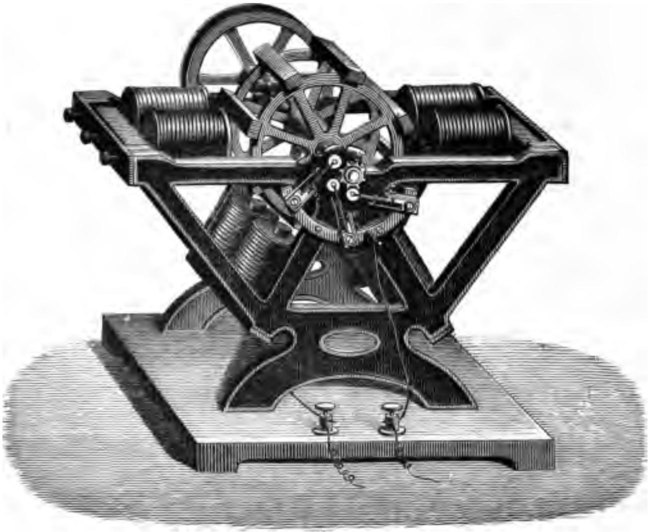
Jacobi, the discoverer of electro-plating, perfected the first motor in 1838. With it he propelled a small boat on the river Neva, in Russia. It consisted of: First, a star-shaped wheel with six points mounted on an axis. Each point had a pair of straight electromagnets arranged on the line of the radius, and perpendicular to it, passing through the star point. Second, two immovable star-shaped wheels of twice as many points, and arranged on either side of the above. Each point carried a horseshoe electromagnet, its arms also arranged on the line of the radius, so that its poles came opposite those of the straight magnets. The commutator was formed of four wheels which so regulated the direction of the current that when the straight magnets were between two consecutive horseshoe magnets, they were repelled from one and attracted toward the other, and at the moment that they came opposite the fixed magnets, the direction of the current was changed, thus changing the polarity of the magnets, causing a repetition of the above motion. In this way, a rotation was maintained.

Many motors were then made in which electro-magnets attracted iron armatures, and when the current was broken, the

armature was moved back to its former position either by another magnet, and by alternate shiftings of the current from one to the other, producing a back and forward motion; or, as in the first motor of Froment, the armatures were mounted on a wooden wheel, as in Fig. 298. The current was sent alternately through two pairs of electro-magnets at a time, thus maintaining a continuous rotation.

Froment's Motor.

FIG. 298.



Froment's Motor.

It has been found that if a current of electricity be passed through a helix, it will draw an iron bar up into it. This principle was employed in the construction of motors by Page, in America, and Bourboze and Du Moncel, in Europe.

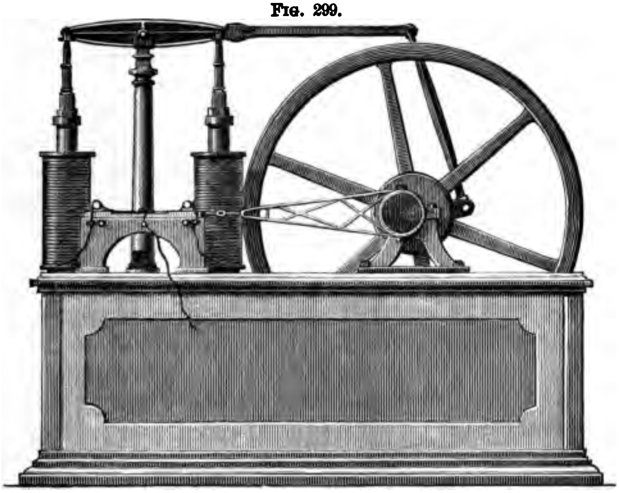
One of these forms is shown in Fig. 299. It consists of two straight electro-magnets (*a*—*b*), whose cores (*f*—*g*) are movable and attached to a beam (*c*), commonly known as a walking-beam, to one end of hich is attached a long arm. When the current is passed rough the magnet (*a*), the core (*g*) is drawn into it, thus

Bourboze's Motor.

drawing up the opposite extremity of the beam. When this beam has reached its highest point, the current is shifted to the magnet (*b*), thus drawing the beam down to its lowest point, when the current is again shifted.

The shifting mechanism consists of a bar (*d*), arranged similar to the eccentric of a steam-engine, and attached to a sliding bar of brass. One wire from the battery is connected with the wire (*e*) and the other with the end wires of the coils,

FIG. 299.



Bourboze's Motor.

the entrance wires of which are attached to the wires adjacent to the coils, as shown. Each of these three wires is attached to pieces of brass, insulated from each other. The sliding bar above mentioned, is long enough to reach across from the middle piece to either end. In the position shown, it is connecting the left-hand pieces, thus sending the current through the magnet (*a*). When in the opposite position, it will send the current through the magnet (*b*).

In the experiment on page 277, it was shown that if a magnet be moved toward a helix, a current is generated in it, and if the magnet be drawn away, a current is generated in the *opposite direction*.

Pixii Machine. This principle was applied by Pixii in the construction of a magneto-electric machine like that on page 279 (Clarke's), except that the magnets revolved and the helices were fixed. Clarke's machine was made afterward, and soon replaced that of Pixii.

The number of bobbins was then increased as well as the number of magnets. The permanent magnets were then replaced by electro-magnets, excited by a smaller magneto-electric machine.

Siemens' Bobbin. Meanwhile, Siemens had been constructing an armature which replaced the numerous bobbins by what is known as the Siemens' bobbin. It consists of a soft iron cylinder grooved longitudinally on opposite sides and on the ends. Wire is wound around the cylinder in these grooves and then connected to insulated portions of the shaft, one end to one, and one to the other, thus forming a commutator which reverses the polarity at every half revolution. Owing to its small diameter, it can be kept in a region of very intense magnetic force. Its weight is about one fifth of the old bobbin armatures of the same power. Owing to its shape, it may be very rapidly rotated.

As stated on page 280, the pole pieces never quite lose their magnetism. Any piece of soft iron once strongly magnetized retains a portion of its magnetism, called residual magnetism. One of the first machines in which this principle was applied, was made by Siemens about the year 1867. This, for the first time, showed that a separate exciting current was not necessary, as explained on page 280.

Gramme Ring. Soon came the Gramme ring which, with its modification, the cylinder armature, forms the most efficient machine. The Gramme ring may be considered as a number of short electro-magnets, each wound in the same direction, so bent that when put together, end to end, they will form a circle, the end wire of one connected with the entrance wire of another, thus forming a complete circuit around a soft iron ring. In practice, a ring of soft iron wires is made, and covered copper wires, of equal length and size, are wound around this in sections of equal width. The connections are made as above indicated, and each

one is attached to a bar of brass. There are as many bars as there are coils, the bars being insulated from one another and fastened longitudinally around an insulating cylinder secured to the axle. In Fig. 300 is a diagrammatic representation of a Gramme ring, showing connections and commutator.

FIG. 300.

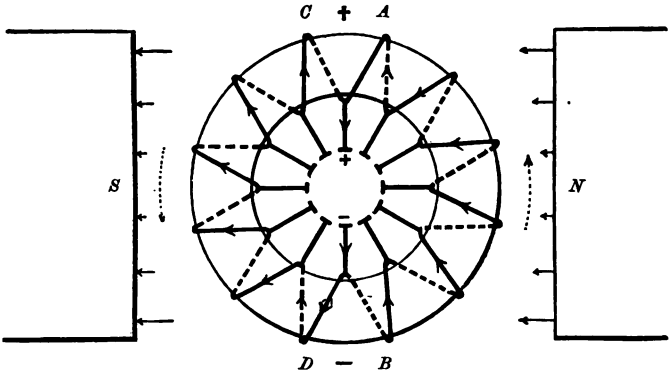


Diagram of a Gramme Ring.

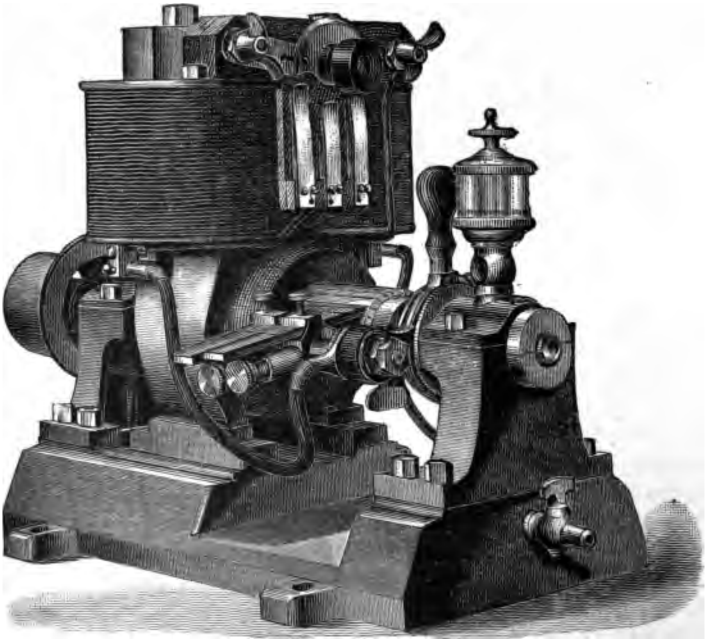
S and N are the poles of the field magnet. The points e, f, g, h, i, etc., are the commutator bars; j, k, l, etc., the connections between the coils. The continuous lines represent the entrance wires, and the dotted lines the exit wires, of each coil. The coils themselves are not shown in the diagram. The points nearest the south and the north poles of the field magnet, are north and south poles, respectively, according to the law of induced magnetism.

Now it is evident that if we revolve the whole armature, it will have the same effect as if we rotated the coil itself; for the core being of soft iron, its poles remain in the same place in relation to the field, no matter how rapidly or slowly the ring is rotated. Revolving the coil alone would have the same effect as dropping a magnet into a helix, only in the former case it is continuous; but we found on page 277, that dropping a magnet into a coil induces a current in that coil; hence, on revolving the armature, a current is induced in the outer coil.

In the portion a—b of the continuous coil, a current is in-

duced which is positive at *a* and negative at *b*. Now, as shown in the previous chapter, the current induced by the south pole of a magnet is the reverse of that induced by the north pole; hence, in the portion *c—d* of the continuous wire, the current is induced in the direction opposite to that in *a—b*, in respect to

FIG. 301.



One Horse-power Incandescent Motor.

the curve of the core, thus bringing the positive pole at *c* and the negative at *d*. The two currents, therefore, oppose each other at the points which are not under the influence of the magnets. These are the points at which the current must be led off, and this is effected by the application of brushes at the points *f* and *g*, as described on page 280. In this way a continuous current is maintained.

It will be seen that in this machine, the commutator is not (as its name would imply) a "current changer," since it serves

merely to send the current through successive coils. It will also be seen that each half of the armature generates but half the current of the machine.

Fig. 302.

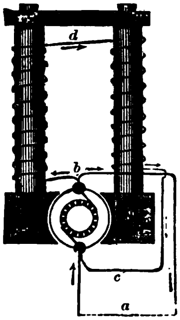


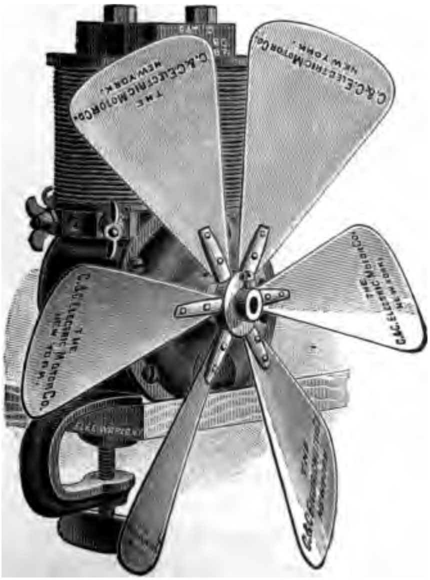
Diagram of Shunt-wound Dynamo.

This machine may be made a motor as well as a generator, and as there is a continuous attraction, there is a continuous rotation, whereas in the older motors the attraction was interrupted, and depended largely on the momentum to carry the armatures out of the magnetic field.

By this means, the former difficulties in the way of the conversion of electricity into motive power were overcome.

Now, it is evident, that the wire on the inner side of the ring is inactive—technically called "dead." Many schemes were tried to render the wire active. Among them the most important is the cylinder armature shown on page 280. In this, the only dead wire is at the ends, which, as can be readily seen, will be much less than that on the inner side of a Gramme ring, especially in long armatures of small diameter.

Fig. 303.



Motor with Fan.

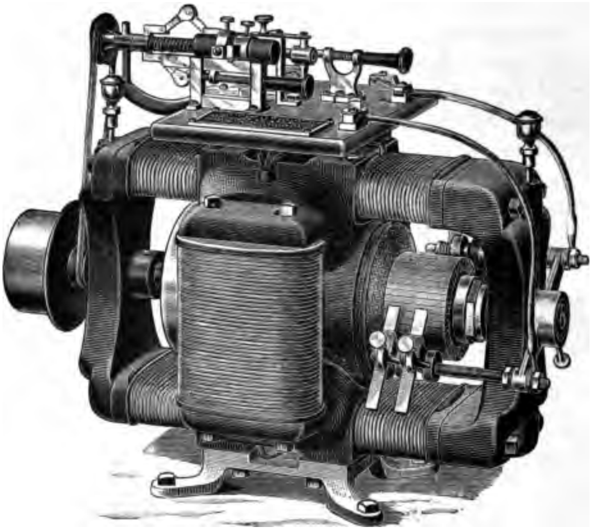
The two armatures last mentioned are the ones most generally employed.

In Fig. 301, one type of motor using the Gramme ring is shown. In some, the field and armature are shunt-wound. This principle is shown in Fig. 302

There are two sets of wires leading from the brushes; one for the external circuit, and the other to excite the field magnets. The dotted line *a* is to represent the external circuit, and the line, *b d c*, the coils of the field magnet.

Motors are made for currents of constant potential with varying current (incandescent circuits), and also for constant currents with varying electro-motive force (arc circuits).

FIG. 304.



Constant Current Motor.

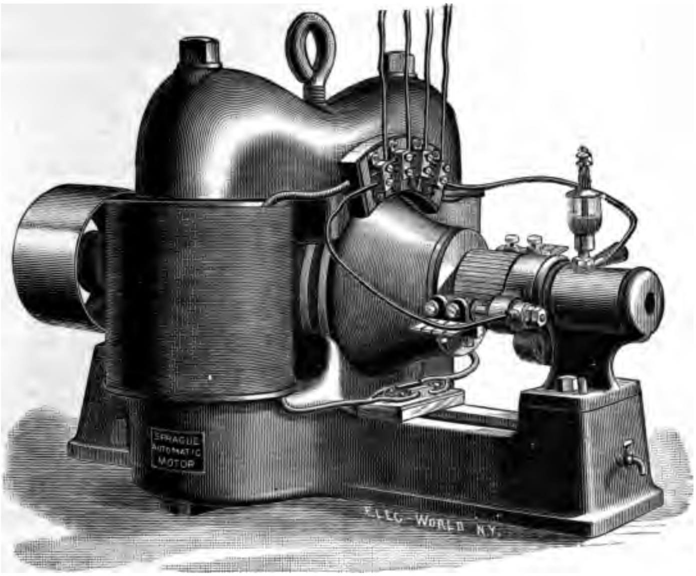
In Fig. 303 is shown one of the smaller sizes of the same style of motor used for rotating a brass fan. It is fastened to the table by means of a clamp and thumb-screw. The capacity 's as high as one eighth of a horse-power, and is intended to be un with a primary battery.

The disposition of commutator, armature, field magnets, etc., ›ing relatively the same in all these machines, will be readily nderstood by reference to page 281.

In Fig. 304 is shown one form of motor to be run with a *urrent of uniform* constancy and varying electro-motive force, *s in arc-light* circuits. It is, consequently, called a constant

current motor. The armature and field of this motor are wound in series (Fig. 295).

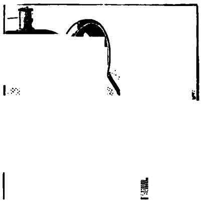
FIG. 305.



Electric Motor.

It will be noticed that, besides the usual field magnets, there are extra branches added, thereby increasing the intensity and steadiness of the field. On the top of the machine is a mechanism for the regulation of speed.

FIG. 306.



Motor on Sewing-machine.

In Fig. 305 is shown a form of motor which is used for elevators, electric street-car lines, and printing-presses. The armature is a modified and improved Siemens, and is connected either in shunt or series, with a field as is desired. It is wound for constant potential.

In Fig. 306 is shown a method of attaching a motor to a sewing-machine. The motor is started and stopped by means of a regulator, operated by the treadle of the machine.

Electric Street-cars.

Among the most important and most rapidly developing applications of the electric motor, is street-car propulsion. Some cars have two motors, some only one. When there are two, each one is placed over an axle, while when there is only one, it is placed between the axles. The connections between the driving-wheel of the motor and the car axles are generally made by a mechanism of cog-wheels, or chain gearing.

The current for the motors is obtained in different ways. In one method two brass pulley wheels are insulated from each other, and each is connected by a wire with one motor brush. The pulley wheels are grooved, and slide on two wires, suspended from poles overhead, and each is connected with one pole of the generator at the central station.

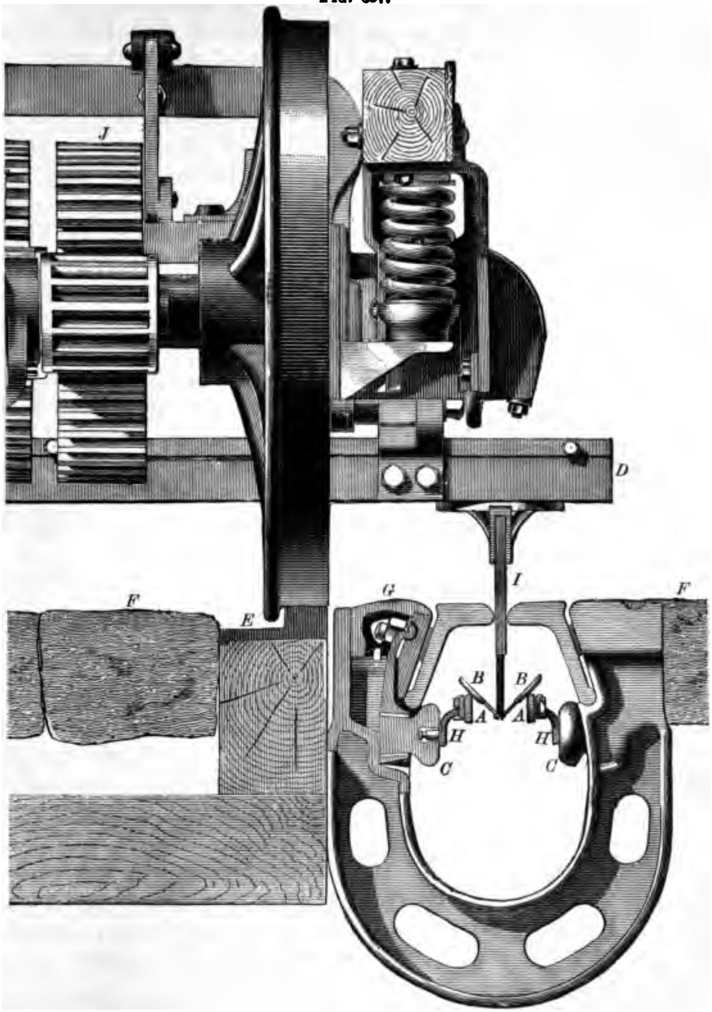
The second method consists in placing the conductors under ground. In Fig. 307 is shown a section of an under-ground conduit, and a portion of the car truck, looking toward the front of it. *A A* are the conductors, made of stout bands of copper, and supported by the metal pieces, *H H*, fastened to the porcelain insulating knobs, *C C*, which are held in place by metal arms, projecting upward into the box covered by the metal cover, *G*, and are bolted to the yoke-piece, as seen. *B B* are spring contacts, insulated from each other. They are the extremities of the so-called "Contact Plow," through which connections are made with the motor by flexible conductors. The head of the plow is held in a guide, *D*, which extends across the entire width of the car, and permits it to slide freely and to follow any variations in the line of the conduit. When a car switches from one track to the other, as at the end of the road, the plow slides the whole length of the guide, as it must occupy a position opposite to that before shown.

Referring again to the cut, *E* is the track, and *F* the pavement. At *J* is shown a portion of the gearing. In this form there are two conduits, one for each track of a double-track road.

The operation is as follows: The contacts, *B B*, are pressed against the bars, *A A*, which are connected at the end of the line with the two poles of the dynamo at the generating station.

The third form (explained below) consists of storage bat-

FIG. 307.



Section of Underground Conduit.

teries, previously charged at the central station, placed under the car seats, and the connections are made with the motor direct.

Storage Battery.

In the electrolysis of water, on page 261, if the battery had been removed, and the wires had then been connected with the wires of a galvanometer, a current would have been indicated by the deflection of the needle. This current will be in the opposite direction to that used in the electrolysis. At the same time the oxygen and hydrogen recombine to form water. This was first noticed in the beginning of the present century. Grove made a gas battery on this principle. Numerous experiments were made until, in 1859, Gaston Planté, a French electrician, discovered that two plates of lead separated by gutta-percha, rolled up and placed in a ten per cent. solution of sulphuric acid, would produce the desired result. The maximum current from this battery, when discharged through a slight resistance, was obtained for a few seconds only. Fauré invented his cell in 1880 (page 262). The trouble with this cell was that the red lead could not be made to adhere to the plate.

FIG. 308.

Storage Battery.

This cell has since been improved as follows (Fig. 308): Fifteen lead plates, seven positive and eight negative, were used. The plates are cast with square holes, contracted in the middle of the plate. The holes in the positive plate were filled with a paste of sulphuric acid, and that oxide of lead known as minium, and the holes in the negative with the oxide called litharge. The paste is held in place by the peculiar shape of the hole.

The seven positive plates are then placed in a jar, between the eight negative, thus leaving the two outside plates negative. As the outside surface of these two plates is inactive, there is no more negative surface than positive. The fluid consists of a dilute solution of sulphuric acid.

When the cell is completed, the current is passed through it, the positive pole of the charging battery being connected with the positive plate of the storage battery, and the negative pole with the negative plate. The minium is reduced to peroxide

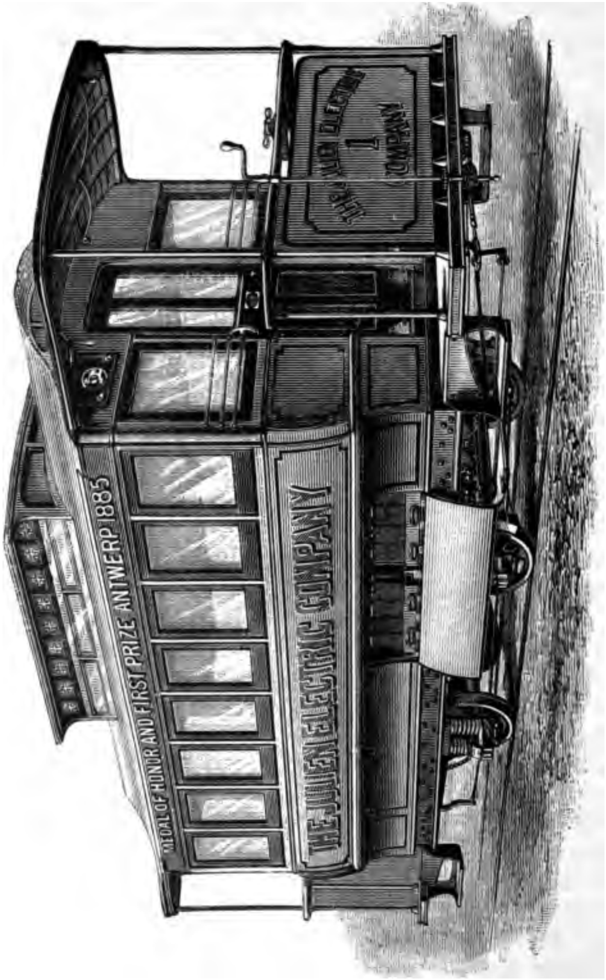
of lead, and the litharge to spongy lead. When the cell is discharged, the peroxide and spongy lead return to their original condition. The average electro-motive force (E. M. F.) is about two volts.

The cells used to propel the car about to be described are similar in form to that just mentioned. The plates consist of a special metallic composition, which, though a secret, is supposed to consist of about ninety-five per cent. lead, with four per cent. antimony, and one of mercury. Plates thus prepared are claimed to be inoxidizable, and will not bend while being charged, as some are apt to do.

The method of using these cells is briefly indicated as follows: The sides of the car below the line of the seats (Fig. 309) are hinged at their lower side, and may be let down as shown. A number of cells containing nineteen plates each are placed in a tray. There is room for four of these trays on each side of the car. On either side of the space allotted for each tray, is placed a block of wood, in which is a spring, pressing upward. There is a piece of metal on each end of the tray, and connected with the positive and negative electrode respectively, so arranged that when the tray is slid into its position in the car, each piece of metal presses against the spring on that side of the tray, thus making an electrical contact. These springs are connected by wires with the regulator-box in the front of the car, by means of which the driver can obtain four different combinations of the cells, thus acquiring four different rates of speed in the motor. By means of a reversing switch he can also make the car go backward as well as forward.

The practical management is as follows: The car comes into the station and moves between two double-decked elevating platforms, the lower decks of which have been placed at the exact height of the battery apartment. The trays are now drawn out of the car on to these decks, the electrical connections being automatically made as in the car. The platforms are then lowered till the upper decks, containing a set of previously charged cells, are on a level with the battery apartment. The trays containing these cells are now pushed into their places in the car. The sides are now raised up and locked, and th car is ready for another trip. The number of cells per ca

Fig. 309.



Storage Battery Car, as used in New York City.

epends on the length of the trip and the grading of the oad-bed. These cars weigh about seven tons, or a little less an *twice* as much as an ordinary horse-car. They are lighted means of incandescent electric lamps.

Small launches have been propelled by means of electricity. Charged storage batteries are placed under the seats, and a motor whose armature-shaft carries a propeller of the same form as is used in steam-launches, is placed in the stern of the boat. The whole arrangement will be understood by reference to Fig. 310.

Electric Launches.

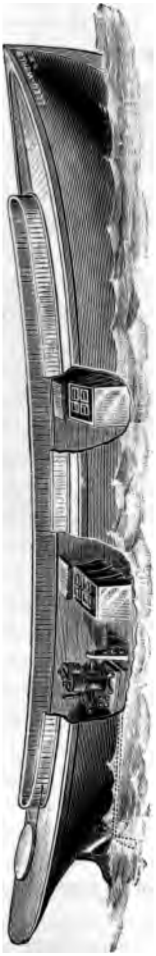
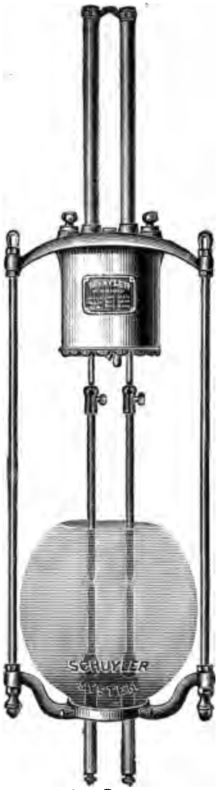


Fig. 310. Electric Launch.

In the previous chapter, page 281, the two kinds of electric light were mentioned. Arc lights are made with single carbons, and for longer duration, or more intense light, some are made with two pairs of carbons. In Fig. 311 is shown one of the latter forms. Before the current is passed, the carbons are together, and by a mechanism of electro-magnets they are drawn apart, and kept at the proper distance.

Fig 311.



Arc Lamp.

The incandescent lamp, Fig. 312, consists of a pear-shaped globe of glass, to the base of which is fastened a brass socket. Platinum wires pass through glass tubes in the socket into the bulb. To the ends of these wires are fastened the U-shaped, or (as in Fig. 313) the corrugated fil-

Electric Ligh

ment of carbon. In the form illustrated, they are attached through the intervention of nickel-plated carbon cylinders, around which are wound the flattened extremities of the platinum wires.

Fig. 312.

Fig. 313.

Incandescent Lamps.

The filaments are made of several different materials,—namely, strips of bamboo, of the proper length and thickness; hardened collodion, rolled in thin plates and cut into strips; and in still another form, cotton twine is treated with sulphuric acid, and then washed.

These filaments are then carbonized by imbedding in pow-
d charcoal and heating to a white heat, or by heating in
ıbago or nickel molds. After this, some are coated with
›n by what is known as the flashing process, which consists

in heating the carbons to incandescence by the electric current or otherwise, while they are in contact with a hydro-carbon gas (*i. e.*, a compound of carbon with hydrogen gas). This process is said to give the lamps longer life.

Incandescent lamps are made from one half candle-power (c. p.) upward, the sixteen c. p. being the one most generally used. An experimental lamp has been made as high as one thousand candle-power.

A sixteen c. p. incandescent lamp requires about ninety-two volts and a current of seven tenths of an amperè. The average durability of a filament is about nine hundred hours.

A number of dynamos are now so made that nearly all the lamps or motors to be run, may be thrown into the circuit, or out at once, without injuring the machines.

Alternating Currents.

Another system of dynamo-electric machinery that is used in certain special cases, is called the Alternating Current System. One of the earliest machines of this class was known as the Lontin Dynamo, and from it, the armature of the machine to be described was developed. This first armature consisted of coils wound on iron cores, radiating from the central axis like the spokes of a carriage-wheel. The field magnets were similarly constructed and of the same number, and were attached to the interior surface of an outer rim inclosing the armature. The form will be understood by reference to Fig. 314.

FIG. 314.

Alternating Current Generator.

These are the principal features of the generator, but there are three essentials in the use of alternating currents. First, the generator; second, the exciter, which is an ordinary, direct current dynamo, used to excite the field coils of the generator above described. This latter is a separately excited machine. The third, and a *very important* feature of this system, is the *converter*.

Converter. These dynamos generate a current of very high potential (one thousand volts, or over), and of comparatively little quantity; and as it would be impossible to use such a current for incandescent lights, it is necessary to resort to a converter, as it is called, which reduces the intensity, and increases the quantity in proportion. This seems odd, but in this connection let it be borne in mind that in the induction coil, when a current of average intensity and quantity was sent through the primary coil, an alternating current of very little quantity and high tension was induced in the secondary coil. Now, suppose we reverse the operation and pass the alternating high potential current through the secondary coil; then we shall have in the primary coil a current of reduced potential and increased quantity. This is the principle of the converter, which will change a current of one thousand volts from the generator, into one of fifty volts, and a correspondingly greater quantity. These converters are placed near to the lamps to be operated by the current.

Fig. 315.

Porcelain Multiple Lighting Burner.

One of the main objects of this system is to be able to convey currents to lamps at a considerable distance, without much loss, and to admit the use of a smaller conducting wire, as a current of large quantity requires a larger wire than one of small quantity.

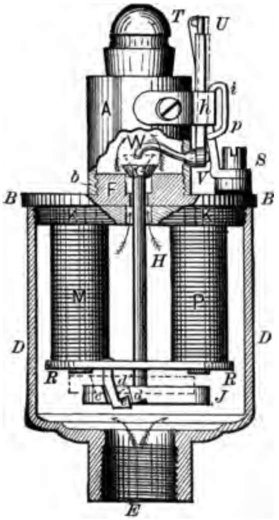
Electricity is much used for lighting gas, especially when the jets are high from the floor and when a large number are to be lighted at once, as in theaters, large halls, churches, etc. For this purpose burners, similar to that shown in Fig. 315, are arranged in series. They are generally lighted by frictional electricity, though sometimes by *uhmkorff* coils.

It is evident that the coil or frictional machine, whichever is used, must be powerful enough to give a spark equal in length to the sum of the distances between the points at the burners. To avoid using machines of great size, only a part of the burners are lighted at once, the current being sent successively through different sets of burners, by means of a switch, thus requiring only a fractional part of the power that would be required to light them all at once.

FIG. 316.

Automatic Burner.

FIG. 317.



Automatic Burner (Cross Section).

Electric gas-lighting burners are also used for lighting several jets independently. Sometimes the gas is turned on and the circuit closed mechanically, and sometimes the whole is operated by the electric current. One of the latter forms is shown in Fig. 316 and a cross section of it in Fig. 317. *D* is a shell containing the helices, four in number, of which only two, *MP*, are shown; the four, by means of the iron disk, *K*, constituting two horseshoe magnets. The armature, J, is suspended below the cores, by means of the valve-stem, H, whic

is attached to the conical valve, *G*. When a current is passed through two of the helices, the armature is raised and rotated to the left into the position indicated by the dotted lines, bringing the recess, *d*, over the hook, *e*, and when the current is broken the armature falls upon this hook, locking it and holding the valve above its seat, permitting egress of the gas.

The spark-producing mechanism, seen in Fig. 317, consists of an arm, *UV*, bent at right-angles and passing through the wall of the tip-socket at *V*, and terminating over the valve at *W*, the point, *V*, constituting a valve and valve-seat, the spring, *ip*, at all times pressing these two parts together and keeping them gas-tight, and at the same time pressing the two platinum sparking points, *UT*, into contact. Therefore, when the valve is first lifted it reaches the termination, *W*, of the vibrating lever, *WVU*, and pressing it upward breaks the circuit at the points, *TU*, producing a spark; as a consequence, a vibrating action, with a continuance of sparking, results as long as the operating key is kept closed with the finger, as in other burners for a similar purpose.

To extinguish the lighted gas, it is only necessary to close the circuit through the other two helices to the ground, when the armature is lifted and rotated free of the locking-hook, and dropped when the circuit is opened at the key.

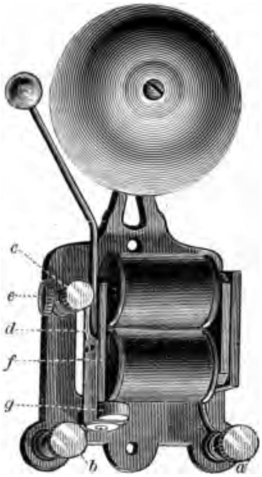
It will be seen that the valve can not be possibly opened by accident; that, on account of the short movement of the armature, but small current is required to operate it. One pair of magnets is operated by one push-button, and the other pair by another. They are used in pairs, mounted on one base.

Another application of electricity is in ringing bells. There are three different forms of bells used,—namely, the vibrating bell, those which strike only as many times as the circuit is completed, and the combined mechanical and electrical gong.

The first is illustrated in Fig. 318. One wire from a battery 's connected with the left-hand binding-post (*b*) and the other vith the right-hand (*a*). The current entering at (*a*) passes rough the coils of the horseshoe electro-magnet and thence by wire to the screw (*c*). Through the side of this screw is ssed a second screw (*e*) with a platinum point, which presses ainst a piece of platinum fastened to the spring (*d*), which is

in turn fastened to the armature (f), and to the metal support (g), which is connected with the other binding-post, thus completing the circuit. When the current passes, the magnet will attract its armature, to which is attached the hammer of the bell. At the same time, it will also pull the spring (d) away from the platinum point of (e), breaking the connection, and consequently as the magnetic influence ceases, the hammer is brought back to its first position by the action of the spring. This again makes the connection, with a repetition of the above movement, causing a rapid vibration of the hammer arm.

FIG. 318.



Vibrating Bell.

In the second form, the current passes directly from the magnet coils to the other binding-post, thus attracting its armature, and holding it there till the circuit is broken. In this form, the spring, and the screws (c) and (e), are often omitted, the bell being then so constructed that the attraction of gravitation will take the place of the spring.

In the third form, the striking mechanism is mechanical, being operated by a spring or weight which has to be wound up at intervals. The electrical part consists of a fixed electro-magnet, whose armature is attached to a catch, which, when lifted by the passage of the current, allows the spring to act on the bell hammer. When the circuit is broken, the catch drops into its place on a cog and prevents the further action of the spring.

The first form is the one used in houses, hotels, and on large steam-boats. When intended to be rung from two or more places, they are generally used in connection with the "annunciator." This consists of a number of electro-magnets, arranged in a box and fastened to the wall. The armatures of the magnets are fastened to catches, which hold up small arms carrying pieces of paper, on which is printed the place from

which that particular magnet can be operated. When the current is passed through the magnet, the catch slips, and the arm drops far enough to allow of the name being read.

The exit wires of all these magnets are connected together and then with one pole of the battery. The other pole is connected with one wire of each push-button, the other wire of which is then connected with the entrance wire of its respective electro-magnet.

The push-button consists of two springs, one above the other, but a little distance apart. One spring is connected with the battery, and the other with one end of its magnet coil, as above indicated. These springs are inclosed in a small box, with a porcelain or metal button resting on the top spring in such a way that, by pressure of the button, the springs are brought into contact, and the circuit completed.

The battery used for operating these small bells is the Leclanché. This consists of a porous cup, and glass jar. In the porous cup is placed carbon and powdered binoxide of manganese, and in the glass cell a zinc rod. The fluid is sal-ammoniac. When the cell is not in use, the zinc corrodes but very little. It is best adapted to ringing bells, and other intermittent work, as when used steadily it soon becomes paralyzed, though it recovers quickly.

SUMMARY.

Matter.

Matter is that which occupies space. A separate portion is called a body, and a particular kind a substance. A general property of matter belongs to all substances, and a specific one to particular kinds. Matter is composed of very minute atoms. A group of atoms forms a molecule, in which reside the specific properties of a substance. A physical change never affects the molecule, but a chemical change breaks it up, and so makes new combinations possible. Physics deals with physical forces and changes; Chemistry with chemical attraction, and chemical changes. Extension and impenetrability are the essential properties of matter. Extension is the property of occupying space. The amount of space a body fills is its volume. In virtue of impenetrability, two bodies can not occupy the same space at the same time. The divisibility of matter is without perceptible limit, so far as we know. Porosity is the property in virtue of which the molecules of a body are not in absolute contact. Indestructibility prohibits the extinction of matter by man. Ductility, malleability, tenacity, elasticity, hardness, and brittleness are the principal specific properties of matter. A ductile body can be drawn into wire; gold, silver, and platinum are the most noted for this property. A malleable body can be hammered into sheets; gold possesses this quality in a remarkable degree. A tenacious body resists pulling apart; iron is the best example. An elastic body permits a play of its particles, so that they return to their original position when the disturbing force is removed. A hard body can not easily be indented. A brittle body is readily broken.

Motion and Force.

Matter, so far as we know it, is in constant change. Change of place is termed motion. Terrestrial motion is restricted by friction, by the air, and by water. Friction is caused by the roughness of the surface over which a body moves. It may be decreased by the use of grease to fill up the minute projections, or by changing the sliding into rolling friction. Air and water must be displaced by a moving body; the resistance they offer is measured by the kinetic energy expended in overcoming it, and is hence proportional to the square of its velocity. Motion takes place in accordance with three laws; viz.: *A moving body left to itself tends to go forever in a straight line; a force has the same effect whether it acts alone or wit other forces, and upon a body at rest or in motion*; and action is equal ar

opposed to reaction. By means of the principles of the composition and resolution of forces, we can find the individual effect of a single force or the combined effect of several forces. Motion produced by two or more instantaneous forces is in a straight line; when one is continuous, the result is a curved line; and when the continuous force, directed toward a fixed point, acts upon a moving body, an ellipse is then described. A circle is one kind of ellipse. A croquet ball struck by two mallets at the same moment, illustrates the first kind of motion; the path of a bullet or rocket in the air exhibits the second; and the movement of a stone whirled in a sling, or of a planet revolving about the sun, is an example of the third. When a rubber ball bounds back from a surface against which it is thrown, the angle of reflection equals the angle of incidence.

Energy, or the power of doing work, is a general term employed to represent the unification of all the forces of nature. The grand law of the Conservation of Energy teaches that the different forces are only forms of one all-pervading energy, and that they are mutually interchangeable, and indestructible as matter itself.—We can not account for its origin, we know not what will finally become of it. We only know its law of action, which we must finally refer to a Supreme Being.

Attraction.

There are certain forces residing in molecules and acting only at insensible distances, which are known as the Molecular Forces. The one which ties together molecules of the same kind is styled cohesion. The relation between this force and that of heat chiefly determines whether a body is solid, liquid, or gaseous. Under the action of cohesion, liquids tend to form spheres; and many solids, crystals. The processes of welding and tempering, and the annealing of iron and glass, illustrate curious modifications of the cohesive force. Molecules of different kinds are held together by adhesion. Its action is seen in the use of cement, paste, etc., in the solution of solids, in capillarity, diffusion of gases, and osmosis.

Gravitation, though weak, compared with cohesion, acts universally. Its force is directly as the product of the attracting and attracted masses, and inversely as the square of their distance apart. As the attraction of gravitation acts so commonly upon great masses of matter, we are apt to consider it a tremendous force. We, however, readily detect its relative feebleness when we compare the weight of bodies with their tenacity. Think how much easier it is to lift an iron wire against gravity than to pull it to pieces against cohesion. Gravity makes a stone fall to the ground. The earth and a kilogram of iron in mid-air attract each other equally, but the mass of the former is so much greater that they move toward each other with unequal velocity, and the motion of the earth is imperceptible. Weight is the measure of the attraction of the earth. At the center of the earth the weight of a body would be nothing; at the poles it would be greatest, and at the equator least. Increase of distance above or far below the surface of the earth will diminish weight. Were the resistance of the air removed, all bodies would fall with equal rapidity. The laws of falling bodies may be studied with the aid of Atwood's Machine. The

first second a body falls 16 ft. (4.9 meters), and gains a velocity of 32 ft. (9.8 meters). In general, the final velocity of a falling body is 32 ft., multiplied by the number corresponding to the second, and the distance is 16 ft. multiplied by the square of the number expressing the seconds. The center of gravity is the point about which the weights of all the particles composing a body will balance one another, *i. e.*, be in equilibrium. There are three states of equilibrium—stable, unstable, and indifferent—according as the point of support in a body is above, below, or at the center of gravity. As the center of gravity tends to seek the lowest point, its position determines the stability of a body. A body suspended so as to swing freely is a pendulum. The time of a pendulum's vibration is independent of its material, proportional to the square root of its length, and variable according to the latitude. The pendulum is our time-keeper and useful in many scientific investigations.

We are so accustomed to see all the objects around us possess weight, that we can hardly conceive of a body deprived of a property which we are apt to consider as an essential attribute of matter. Nothing is more natural, apparently, than the falling of a stone to the ground. "Yet," says D'Alembert, "it is not without reason that philosophers are astonished to see a stone fall, and those who laugh at their astonishment would soon share it themselves, if they would reflect on the subject." Gravity is constantly at work about us, at one moment producing equilibrium or rest, and at another, motion. When it seems to be destroyed, it is only counterbalanced for a time, and remains, apparently, as indestructible as matter itself. The stability and the incessant changes of nature are alike due to its action. Not only do rivers flow, snows fall, tides rise, and mountains stand in obedience to gravitation, but smoke ascends and clouds float through the combined influence of heat and weight.

Elements of Machines.

All machines can be resolved into a few elementary forms. Of these there are six, viz., the lever, the wheel and axle, the inclined plane, the screw, the wedge, and the pulley. Though called the mechanical powers, they are only instruments by which we can avail ourselves of the forces of nature. Molar energy or the motion of masses, as of air, water, steam, etc., is thus utilized, while the strength of a horse does the work of many men. A force of small intensity made to act through a considerable distance becomes one of great intensity acting through a small distance, and vice versa. By the use of the mechanical powers, the application of energy is made more convenient, but always some energy is absorbed in moving the machine and overcoming friction, and hence prevented from doing useful work. No machine can be a source of power, but, on the contrary, it thus involves a loss of power. The law of machines is, that the power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it moves, plus the internal work involved in the motion of the machine. This law is equivalent to a statement that perpetual motion is impossible; for no known terrestrial source of energy is exhaustless,

The lever is a bar resting at some point on a prop as a center of motion. The crowbar, claw-hammer for drawing nails, pincers, windlass, and steelyard are examples of various classes of levers. The compound lever consists of several levers, so connected, that the short arm of one acts on the long arm of the next, as in the hay scales. In the bent lever, the power and weight act in lines that are not necessarily parallel, but still tend to produce rotation of the lever about its fulcrum, if the product of the power by the perpendicular distance from its line of action to the fulcrum be not equal to the weight multiplied by the distance from its line of action to the fulcrum. These two products are called the moments about the fulcrum. If the two moments are equal and opposite, the result is equilibrium.

To the lever may be reduced the wheel and axle, and the pulley. To the inclined plane may be reduced the wedge and the screw. The awl, vise, carpenter's plane, corkscrew, and stairs are common modifications of the inclined plane. The blade of a pocket-knife is a familiar example of the wedge, which itself is only a movable inclined plane. In the application of these last mechanical powers, friction becomes a most important and useful element; and it interferes so much with the operation of the simple machine alone, which should be devoid of friction in order to make exact calculation possible, that it is usually impossible to calculate the ratio between the power applied and the work accomplished through the medium of a wedge.

Hydrostatics treats of the laws of equilibrium in liquids. Pressure is transmitted by liquids equally in every direction. Water thus becomes a "mechanical power," as in the "Hydraulic Press." Liquids acted on by their weight only, at the same depth, press downward, upward, and sidewise with equal force. This pressure is independent of the size of the vessel, but increases with the depth. Wells, springs, aqueducts, fountains, and the water-supply of cities illustrate the tendency of water to seek its level. The ancients understood this law, but had no suitable material for making the immense pipes needed; just so the art of printing awaited the invention of paper. Specific gravity, or the relative weights of the same volume of different substances, is found by comparing them with the weight of the same volume of water. This is easily done, since, according to the law of Archimedes, a body immersed in water is buoyed up by a force equal to the weight of the water displaced; *i. e.*, it loses in weight an amount equal to that of the same volume of water.

Pressure of Liquids and Gases.

$$\text{Hence spec. grav.} = \frac{\text{weight in vacuum}}{\text{weight in vacuum} - \text{weight in water}}.$$

A floating body displaces only its own weight of liquid. This explains the buoyancy which supports a ship, why a floating log is partly out of water, and many similar phenomena.

Hydrodynamics treats of moving liquids. The laws of falling bodies in *theory apply;* so that a descending jet of water will acquire the same *velocity that a* stone would in falling to the ground from the surface of

the water; and an ascending jet would need to have the same velocity in order to reach that height. The quantity of water discharged through any orifice equals the area of the opening multiplied by the velocity of the stream. The chief resistance to the motion of a liquid is the friction of the air and against the sides of the pipe, and, in the case of rivers, against the banks and bottom of the channel. The force of falling water is utilized in the arts by means of water-wheels. There are four kinds—overshot, undershot, breast, and turbine. The principles of wave-motion, so essential to the understanding of sound, light, etc., are most easily studied in connection with water. A stone let fall into a quiet pool sets in motion a series of concentric waves, whose particles move in ellipses, while the movement passes to the outermost edge of the water, and is then transmitted to the ground beyond. The velocity of the particles is much less than that of the wave itself. A handful of stones acts in the same way, but sets in motion many series of waves. Hence arise the phenomena of interference.

Pneumatics treats of the properties and the laws of equilibrium of gases. The air being composed of matter, has all the properties we associate with matter, as weight, indestructibility, extension, compressibility, etc. The elasticity of the air, according to Mariotte's law, is inversely proportional to its volume, and this is inversely proportional to the pressure upon the air; both heat and pressure increasing the elasticity of a gas. The air, like other fluids, transmits the weight of its own particles, as well as any outside pressure, equally in every direction; hence the upward pressure or buoyant force of the atmosphere. A balloon rises because it is buoyed up by a force equal to the weight of the air it displaces. It floats in the air for the same reason that a ship floats on the ocean. When smoke falls it is heavier than the surrounding atmosphere. When it rises, it is carried up by adhesion of warm air, which is lighter than that surrounding the current. The air-pump is used for exhausting the air from a receiver, and the condenser for condensing the air. A vacuum in which there remains only $\frac{1}{1\,000\,000}$ of the atmosphere can be obtained by means of Sprengel's air-pump, which acts on the principle of the adhesion of the air to a column of falling mercury. The average pressure of the air being 15 lbs. to the square inch, equals that of a column of water 34 ft., and of mercury 30 inches or 760 millimeters high. This amount varies incessantly through atmospheric changes caused by alterations in the wind, heat of the sun, etc. The barometer measures the pressure of the atmosphere, and is used to determine the height of mountains and the changes of the weather. The action of the siphon, the pneumatic inkstand, and of the different kinds of pumps, is based upon the pressure of the air.

Sound.

Sound is produced by vibrations. These are transmitted in waves through the air (60° F.) at sea-level at the rate of 1,120 ft. per second; through water four times, and through iron fifteen times as fast. In general, the velocity depends on the relation between the density and the elasticity of the medium; *and the intensity is* proportional to the square of the amplitude of the

vibrations. Sound, like light, may be reflected and refracted to a focus. Echoes are produced by the reflection of sound from smooth surfaces, not less than 112 ft. (about 33 meters) distant. Several acoustic phenomena have become of historical interest. Near Syracuse, Sicily, is a cave known as the Ear of Dionysius. A whisper at the farther end of the cavern is easily heard by a person at the entrance, though the distance is 200 ft. Tradition says that the Tyrant of Syracuse used this as a dungeon, and was thus enabled to listen to the conversation of his unfortunate prisoners. On the banks of the Nile, near Thebes, is a statue 47 ft. high, and extending 7 ft. below the ground. It is called the Vocal Memnon. Ancient writers tell us that about sunrise each morning, there issued from this gigantic monolith a musical sound resembling the breaking of a harp-string. It is now believed that this was produced by friction due to unequal expansion of different parts under the morning sun. Near Mount Sinai, in Arabia, remarkable sounds are produced by the sand falling down a declivity. The sand, which is very white, fine, and dry, lies at such an angle as to be easily set in motion by any cause, such as scraping away a little at the foot of the slope. The sand then rolls down with a sluggish motion, causing at first a low moan, that gradually swells to a roar like thunder, and finally dies away as the motion ceases.

Rapidly-repeated vibrations make a continuous sound; regular and rapid vibrations produce music; irregular ones cause a noise.

The pitch of a sound depends on the rapidity of the vibrations. The number of waves, and their consequent length in a given sound, is found by means of the siren. Unison is produced by identical wave-motions. Any number of sound-waves may traverse the air, as any number of water-waves may the surface of the sea, without losing their individuality. The motion of each molecule of air is the algebraic sum of the several motions it receives. Two systems of waves may therefore destroy or strengthen each other, according as they meet in opposite or in similar phases. Interference is the mutual weakening of two systems of waves which meet in opposite phases. Beats are the effect produced by two musical sounds of nearly the same pitch, which alternately interfere and coalesce. The vibrations of a cord produce a musical sound, which is re-enforced by a sounding-board. The rate of vibration and consequent pitch depends on the length, the tension, and the weight of the cord. A sounding body vibrates not only as a whole, but also in segments. Its vibration as a whole produces the fundamental tone, and the additional vibration in segments gives rise to the overtones. These together form either a complete or an interrupted harmonic series. The quality of the compound sound depends on the number, orders, relative intensities, and mode of combination of the overtones into which it can be resolved. The various notes in the musical scale are determined by fixed portions of the length of the cord. The music of a wind instrument is produced by vibrating columns of air. Resonance is a sympathetic vibration caused by one sonorous body acting on another, *through* a conducting medium, as seen in the resonance globe, etc. The *voice is* a reed instrument, with its vibrating cords and resonant

cavity. The ear collects the sound-waves. It consists of the outer ear, the drum, and the labyrinth. The auditory nerve transmits to the brain the sensations produced in the ear by sound-waves.

Light.

Light comes from the sun and other self-luminous bodies. It is transmitted by means of vibrations in ether, in accordance with the laws of wave-motion. It is radiated equally in all directions, travels in straight lines, decreases as the square of the distance increases, and is propagated 186,000 miles per second. Light falling upon a body may be absorbed, transmitted, or reflected. If the surface be rough, the irregularly-reflected light enables us to see the body; if it be smooth and highly polished, the rays are reflected so as to form an image of the original object. Surfaces producing such images are termed mirrors—plane, concave, or convex. The image is seen in the direction from which the reflected ray enters the eye, and, in a plane mirror, as far behind the mirror as the object is in front. Multiple images are produced by repeated reflections, as in the kaleidoscope. A concave mirror, as generally used, collects the rays, and serves to produce either a magnified erect virtual image or a magnified or diminished inverted real image of an object. A convex mirror scatters the rays, and diminishes the apparent size of an object.

When a ray enters or leaves a transparent body obliquely, it is refracted; if passing into a rarer medium, it is bent away from the perpendicular erected at the point of incidence; if into a denser medium, it is bent toward this perpendicular. A lens is a transparent body with one or more curved surfaces, which are usually spherical, so as to refract the light either to a focus, or as if it had come from a focus. There are two classes—convex and concave. The former lens, as generally used, tends, like a concave mirror, to collect the rays of light; the latter, like a convex mirror, causes the rays of light to diverge. Mirage is an optical delusion caused by refraction of light in passing through air composed of strata of unequal density. Owing to the varying refrangibility of the different waves of the sunbeam, a prism can disperse them into a colored band called the solar spectrum. The spectrum shows white light to consist of many tints, and that the solar energy may produce luminous, heating, or chemical effects according to the nature of the body receiving it. By means of the spectroscope we can examine the spectrum of a flame, and find whether its light is due to the burning of a gas alone, or to the glowing of denser particles diffused in it. Each substance in the gaseous state gives a spectrum with its peculiar lines of color. A gas absorbs the same rays that it is capable of emitting; if, therefore, a burning gas or vapor is interposed between the eye and a glowing solid, the spectrum of the solid is interrupted by dark lines due to absorption by the vapor. A delicate mode of analysis is thus furnished, whereby the elements even of the distant stars can be detected. The rainbow is formed by the refraction and reflection of the sunbeam in rain-drops. Light, when reflected by or transmitted through bodies, is so modified, chiefly by absorption, as to produce the varied phenomena of color. Each color has its own wave-length, which

is less than $\frac{1}{35000}$ inch. Different systems of light-waves, as of sound-waves, may be combined. But if any two coincide with similar phases they will strengthen each other; and if with opposite phases, weaken each other. Interference of light, as thus produced, causes the play of colors in the soap-bubble, mother-of-pearl, etc. Polarized light is that in which the molecular vibrations are made in the same plane. Many of the most beautiful color effects may be produced by polarization.

The principal optical instruments, including the eye, are adapted to produce and examine the image formed by a lens. In the projecting lantern and solar microscope, the image is thrown on a screen in a dark room. In the refracting telescope and the microscope, the image is formed in a tube by a lens at one end and looked at from behind by a lens at the other end. In the eye, which is a small camera-obscura, the image is formed on the retina, whence the sensation is carried by the optic nerve to the brain. The retinal sensation continues for a short time after the impression is made. Advantage is taken of this fact in the use of the zoetrope, by which a succession of images is made to appear in motion. Vision with two eyes is superior to that with a single eye, because we are thus enabled to form better ideas of depth in space, and hence of the distance and form of a body. The stereoscope is an instrument for studying the peculiarities of binocular vision.

Heat.

Heat is produced by longer and less refrangible waves and slower vibrations of ether than those which cause light. Solar energy may be radiated, reflected, refracted, absorbed, and polarized, whether manifested as light or heat. If we elevate the temperature of a body sufficiently, such as a piece of platinum, we can cause it to emit rays of both heat and light. A body which allows the radiant heat to pass through it easily is styled diathermanous; rock-salt is such a body, being to heat-rays what glass is to light-rays. The sun is the principal source of heat. But heat can be obtained by chemical and mechanical means. In burning coal we secure it by the former method. Mechanical energy may be changed directly into heat, as in striking fire with flint and steel, and in hammering a bullet on an anvil until it is hot. According to Joule's law, 772 feet fall of a given weight corresponds to 1° of rise of temperature in the same weight of water.

Among the physical effects of heat are a change of temperature, expansion, liquefaction, vaporization, and evaporation. The heat-force increases the kinetic energy of the molecules, thus elevating the temperature; and the increased vibration of the molecules causes an expansion of the body. The latter is so uniform in certain substances, such as mercury, that it is used to indicate changes of temperature, as in the thermometer. The expansion of the metals by heat is turned to account in many art processes. The walls of a gallery in the Conservatoire des Arts et Metiers, in Paris, had begun to bulge. To remedy this, iron rods were passed across the building and screwed into plates on the outside of the walls. By heating the bars, they were expanded, when they were screwed up tightly. Being then allowed to cool, they contracted, thus drawing the walls back

toward a perpendicular. The same has been done for weakened walls in many other places.

Heat is the great antagonist of cohesion. The liquid and gaseous states of bodies depend on its relative presence or absence (absolute cold is as yet only a theoretical condition, all bodies with which we are familiar being relatively warm). When the heat-force nearly balances that of cohesion, the body breaks down into a liquid, and when the repellent fairly triumphs, the particles fly off as a gas. Immediately before and after each of these marked changes, viz., of a solid to a liquid and of a liquid to a gas, the thermometer indicates a constant temperature. Thus, water from melting ice affects the thermometer just as the ice does, and steam is no hotter than the boiling water. The heat which, in these processes, becomes hidden from the thermometer is called latent, though we now know that, having been occupied in doing internal work, it has merely become potential, and can be readily turned again into kinetic energy. The so-called latent heat of water is only the potential heat-energy of the separated molecules, which will re-appear the instant the molecules collapse and come once more within the grasp of cohesion. On this principle is based the method of heating by steam. Evaporation is a slow change to vapor that takes place at all temperatures, but may be greatly increased by a diminution of pressure, as in a vacuum. It is a cooling process, and is practically applied to the manufacture of ice.

By the subtraction of heat, *i. e.*, by cold, and by the addition of pressure, which antagonizes the repellent heat-force, gases may be liquefied and even congealed, the transparent carbonic-acid gas thus becoming a snowy solid. What were formerly called the "permanent gases" (oxygen, hydrogen, etc.), have been liquefied by means of the cold produced by their rarefaction when they were suddenly released from a pressure of two or three hundred atmospheres.

Heat is conducted from molecule to molecule of a body, radiated in straight lines through air (or space), and circulated by the transference of heated masses through a change of specific gravity due to expansion. The first method is characteristic of solids, and the third of liquids and gases. The elastic force of steam increases when it is confined and a higher temperature is reached. The steam-engine utilizes this principle. There are two forms of this machine, the high-pressure and the low-pressure, according as the waste steam is ejected into the air or condensed in a separate chamber. The phenomena of dew, rain, etc., depend upon the fact that a change from a higher to a lower temperature causes the air to deposit its moisture.

Magnetism.

Natural magnets are found in certain regions, but in practice, magnets made of steel are generally used. These bars may be magnetized either by contact with other magnets or by placing them within the magnetic field of a coil conducting an electric current (see p. 251). The existence of magnetism is manifested by polarity. Like poles repel, unlike attract each other. The intensity of the force varies inversely as the square of the distance. A magnet indu

magnetism in any neighboring magnetic body. This is not prevented by intervening bodies which are not themselves magnetic. If free to move, small bodies thus influenced by induction tend to place themselves in certain directions, called lines of force, around the inducing magnet. The declination, the dip, and the intensity are the magnetic elements of a place. Each of these is subject to daily variations, and additionally to slow changes requiring many years for a cycle. The cause of the earth's magnetism is unknown. Sudden variations in it accompany the outbreak of spots on the sun and magnetic storms are usually attended by the appearance of the aurora.

Electricity.

Electricity is a form of energy that may be manifested as an accompaniment of friction, of chemical action, of the motion of magnets, of variations in temperature, or of animal excitement. It exhibits a certain kind of duality in its effects, and hence the names positive and negative electricity are used to express the contrast. Many considerations point to the conclusion that the molecules of a charged body are in a condition of strain. This condition can be communicated by induction through a "dielectric," which itself becomes strained while thus acting as a medium. By taking advantage of a proper dielectric, such as glass, electrical energy may be stored up for subsequent use, as in the Leyden jar.

Voltaic electricity has its origin in chemical action, or in contact of different metals, or in both. The essentials of an ordinary battery for its development are two substances, which are unequally affected by a chemical agent. One of these is at higher potential than the other, and neutralization is effected by the passage of a current, continually renewed, from the body at high potential, through the best conductor, to the body at low potential. This difference of potential, however, is very slight in comparison with that developed by friction and induction, as in the Holtz or Voss machine. Voltaic electricity is more manageable, more reliable, more convenient, more generally available than frictional electricity. Electricity may be transformed, under appropriate conditions, into mechanical motion, magnetism, sound, heat, or light. Among its most important applications to the purposes of practical life are the telegraph, the electrotype, the telephone, and the electric light.

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The **Black-board Analysis.** See p. 314 as an example of this marked feature.

The exquisite **Illustrations**, unrivalled by any text-book. See pp. 9, 457, and 582, as samples of the 240 cuts contained in this beautiful work.

The peculiar **Summaries**, and valuable lists of **Reading References.** See p. 417.

The numerous and excellent colored **Maps.** These are so full as to answer for an extensive course of collateral reading, and are consequently useful for reference outside of class-work. See pp. 299 and 317.

The Scenes in Real Life, which are the result of a careful study of the collections and monuments in the London, Paris, and Berlin museums, and the latest authorities upon the domestic life of the people of former times. See pp. 38–39. This scene — a Lord of the IVth Dynasty — is mainly a transcription of details to be found painted on the walls of Egyptian tombs.

The chapters on **Civilization** that attempt to give some idea of the Monuments, Arts, Literature, Education, and Manners and Customs of the different nations. See pp. 171, 180, 276, 279, 472, and 514.

The admirable **Genealogical Tables** interspersed throughout the text. See pp. 340 and 494.

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The peculiar method of treating **Early Roman History,** by putting in the text the facts as accepted by critics, and, in the notes below, the legends. See pp. 205–6.

The exceedingly useful plan of running collateral history in parallel columns, as for example on p. 361, taken from the Hundred Years' War.

The **Historical Recreations,** so valuable in arousing the interest of a class. See p. xi from the Appendix.

The striking opening of Modern History on pp. 423–4.

The interesting **Style,** that sweeps the reader along as by the fascination of a novel. The pupil insensibly acquires a taste for historical reading, and forgets the tediousness of the ordinary lesson in perusing the thrilling story of the past. See pp. 251–2.

Special attention is called to the chapter entitled **Rise of Modern Nations,** — England, France, and Germany. The characteristic feature in the mediæval history of each of these nations is made prominent. (*a.*) After the Four Conquests of England, the central idea in the growth of that people was the Development of Constitutional Liberty. (*b.*) The feature of French history was the conquest of the great vassals by the king, the triumph of royalty over feudalism, and the final consolidation of the scattered fiefs into one grand monarchy. (*c.*) The characteristic of German history was disunion, emphasized by the lack of a central capital city, and by an elective rather than an hereditary monarchy. The struggle of the Crown with its powerful vassals was the same as in France, but developed no national sentiment, and ended in the establishment of semi-independent dukedoms.

These three thoughts furnish the beginner with as many threads on which to string the otherwise isolated facts of this bewildering period.

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